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CONTRACT NO: DAAK70-87-C-0061

FINAL REPORT

SDMHE DRIVELINE BENCHTEST

SUBMITTED TO

U.S. ARMY

BELVOIR R, D, & E CENTER

FT. BELVOIR, VIRGINIA

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<p>(U) Laboratory testing was conducted on driveline components approved by the U.S. Army. The purpose of testing was to evaluate the acceptability of existing driveline components for use in the U.S. Army's proposed Self Deployable Materials Handling Equipment (SDMHE). The proposed SDMHE differs from past and present Rough Terrain Forklifts in that it must be capable of 45 miles per hour transport speeds. The driveline components tested were selected based upon ability to meet the required SDMHE performance specification, availability, cost, and reliability.</p> <p>(U) Test results indicate that engines, torque converter power shift transmissions and drive shafts do presently exist which would perform acceptably on the SDMHE.</p>				
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Figure 8. Report Documentation Page, DD Form 1473 (1 of 2)

- (U) Test results indicate that existing axle assemblies which will perform acceptably on the SDMHE may be more difficult to find. The two major problems found on the tested axle assembly were (1) excessive oil temperature during high speed transport and (2) inadequate gear train strength during materials handling operations. *Revised*

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Figure 8. Report Documentation Page, DD Form 1473 (2 of 2)

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## 1.0 INTRODUCTION

The U.S. Army has a need for Rough Terrain Materials Handling Equipment that is Self-Deployable. Forklifts that are self-deployable (capable of 45 MPH operation) will be able to travel under their own power while moving in convoy. Currently, when rough terrain forklifts need to deploy or relocate over long distances, they must be loaded onto equipment carriers and carried to their new location. This procedure ties up both equipment and personnel which would otherwise be available for moving additional supplies.

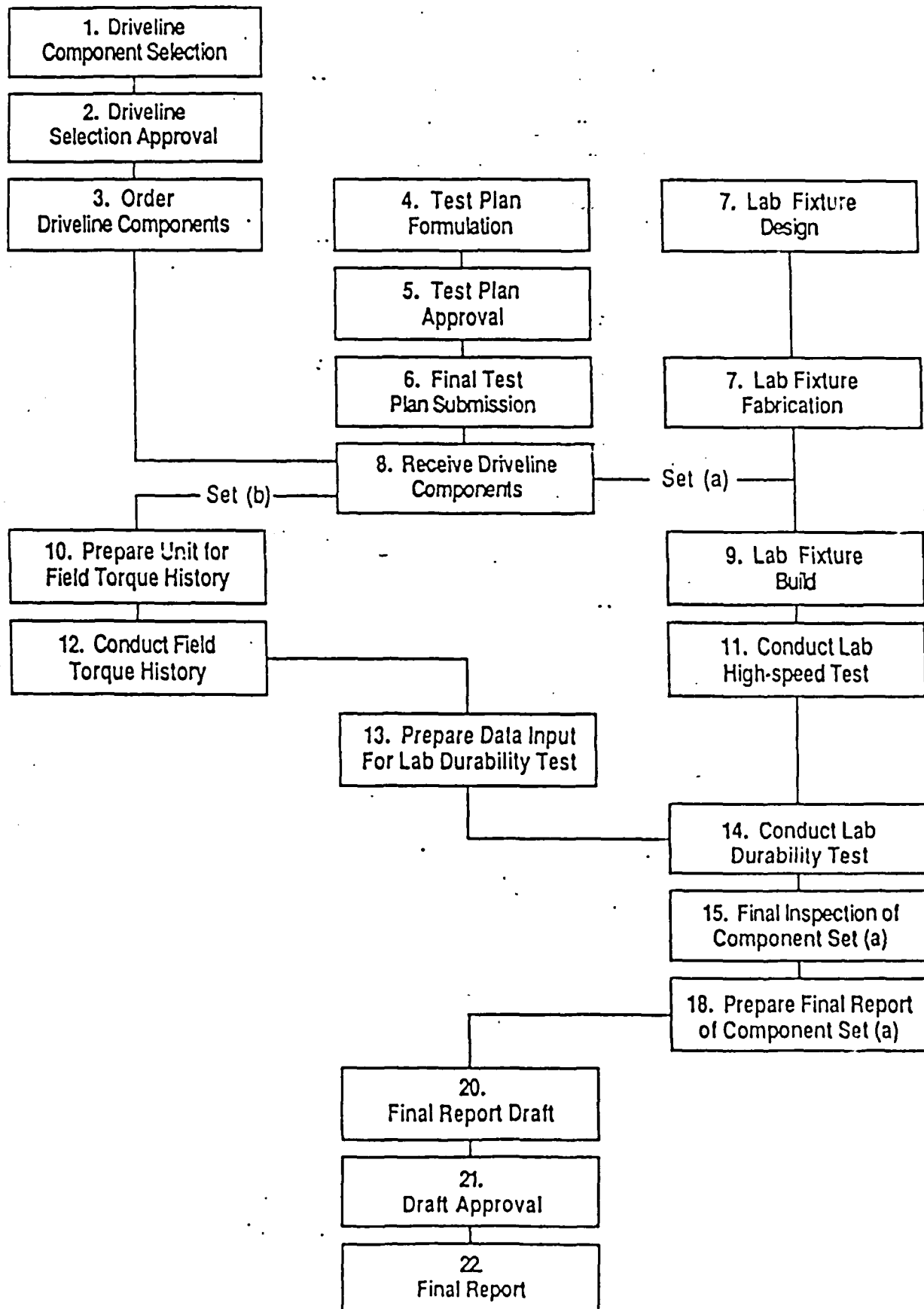
The U.S. Army completed a study which determined that a Self-Deployable Materials Handling Equipment (SDMHE) vehicle is feasible. The conclusion of the feasibility study was that component manufacturers presently have available, commercial componentry which would satisfy the requirements of SDMHE of 4,000 lb., 6,000 lb., and 10,000 lb. capacities.

The U.S. Army established performance requirements for the 10,000 lb. capacity SDMHE vehicle as well as laboratory durability test requirements for the driveline components. Solicitation DAAK70-87-R-0110 was issued for the purpose of selecting a contractor who would, subject to U.S. Army approval, select driveline components, develop the test cycle, and conduct the testing.

Deere & Company was awarded U.S. Army Contract No. DAAK70-87-C-0061 for testing services on driveline components for the Self-Deployable Materials Handling Equipment (SDMHE). These testing services include selection of driveline components, development of a laboratory test cycle, and conducting the required laboratory tests. The objective is to analyze, by actual testing, the acceptability of existing driveline components for the SDMHE application.



# Figure 1 - Flow Chart for SDMHE Driveline Testing



## 2.0 OVERALL TEST PROCEDURE

Figure 1 is the flow chart of Activities 1 through 22, as proposed by Deere & Company and approved by the U.S. Army, for the overall test program. These activities are detailed in the Final Test Plan (dated 03 February 1988) for the Contract DAAK70-87-C-0061.

Deere & Company selected driveline components which were approved by the U.S. Army. These components were selected to fit within the basic machine confines of the John Deere 644E Four Wheel Drive Loader for testing purposes. The wheel loader frame was reworked to provide proper location of mounting points for the engine, torque converter, transmission, and front and rear axle assemblies.

The laboratory test vehicle consisted of a complete set of driveline components mounted in a reworked John Deere 644E machine frame. A load dynamometer was attached to the end of each hub, where the vehicle wheels would normally be attached. Testing was conducted with input power from the engine and computerized control of the load dynamometers to provide the required resistance torque at the axles.

The high speed transport portion of the testing was run separately of the low speed (materials handling) portion of lab testing. The two were separated because high speed, low torque requirements of Activity 11 (Figure 1) required a significant difference in number of friction components and cooling in the load dynamometers than the low speed, high torque requirements of Activity 14 (Figure 1).

Loading for the high speed (transport) portion of laboratory testing was based upon calculated torque and RPM at the axles. Load input data for the low speed (materials handling) portion of laboratory testing was provided by running a field histogram (Activities 12 and 13 - Figure 1). To obtain the field histogram, a second set of the chosen driveline components were installed in a second reworked John Deere 644E vehicle frame. This unit was then built experimentally into a completely functioning 10K Forklift Truck equipped for field materials handling operations (Activity 10 - Figure 1).

Table I: Assumed Field Operation Composite for SDMHE

<u>Field Operation</u>	<u>Percent of Total Machine Life</u>
1. Materials Stockpiling (On improved surface)	10
2. Materials Stockpiling (On unimproved surface)	20
3. Materials Stockpiling (On beach surface)	<u>5</u>
A. TOTAL MATERIAL STOCKPILING	35.0
4. Material Transport (low speed-improved surface)	10
5. Material Transport (low speed-unimproved surface)	15
6. Material Transport (low speed-over crossties)	5
7. Material Transport (low speed-thru potholes)	<u>5</u>
B. TOTAL MATERIAL TRANSPORTING	35.0
8. Transport w/o Load (45 MPH on hills with 2% grade - improved surface)	4
9. Transport w/o Load (40 MPH on hills with 3% grade - improved surface )	2
10. Transport w/o Load (45 MPH on level improved surface)	2
11. Transport w/o Load (20-30 MPH on hills with 2-3% grade - firm unimproved surface)	<u>7</u>
C. TOTAL TRANSPORTING W/O LOAD (ROADING)	15.0
D. 12. SPECIAL PERFORMANCE (2 MPH up 45% grade unimproved surface, w/10,000 lb load)	0.1
E. TOTAL NON-DAMAGE PRODUCING OPERATIONS	14.9

Table I basically identifies the different field operations expected and assigns an expected percentage of total machine field life to each field operation.

## 2.0 OVERALL TEST PROCEDURE (Continued)

The field operations conducted to obtain the driveline loading histogram were based upon an assumed field operation composite for the Self-Deployable Materials Handling Equipment. Table 1 shows this assumed field operation composite as used for this test program. Material stockpiling (Operations 1, 2, and 3), material transport (Operations 4, 5, 6, and 7), and transporting material at 2 MPH up a 45 percent slope (Operation 12) were conducted for the histogram, using the experimentally built field SDMHE machine. High speed transport (Operations 8, 9, 10, and 11) was not conducted for histogram recording because the experimentally built vehicle did not have adequate steering and suspension systems for controlled 45 MPH operation. The requirements of high speed transport (Operations 8, 9, 10, and 11) were used in calculating the loading for the high speed portion of laboratory testing.

Laboratory transmission clutch testing (Activities 16, 17, and 19) which were on Figure 1 as part of the final test plan, were deleted from the test program as of 19 July 1988 per agreement with Mr. D. Krawchuk, U.S. Army. The purpose of these three activities was to conduct a separate laboratory evaluation test of transmission clutches. This is normal procedure by Deere & Company because transmissions are not shifted under load during the lab durability testing (Activity 14 on Figure 1). However, for meaningful transmission clutch test results, the transmission shift modulation characteristics must be the same as for the final vehicle. After installing the selected transmission in the SDMHE experimentally built field vehicle, it became apparent that an additional development program would be required to get transmission shift modulation to a satisfactory condition for a final vehicle. This prospect of added time and expense, plus the fact that planned laboratory transmission clutch testing (Activities 16 and 17) would make use of test components from the experimentally built field vehicle was the primary rationale for deleting laboratory transmission clutch testing (Activities 16 and 17). The U.S. Army had become interested, at this time, in keeping the experimentally built SDMHE field vehicle intact.

All laboratory testing of driveline components was accelerated based upon DAMAGE. DAMAGE is a value which combines the effects of torsional magnitude and rotational speed upon fatigue life of any torque transmitting component of the driveline. It is expressed in terms of DAMAGE cycles per hour.

## 2.0 OVERALL TEST PROCEDURE (Continued)

Contract DAAK70-87-C-0061 required 2000 hours of laboratory testing on a set of selected driveline components. The final test plan breakdown of this was 462 hours of high speed (gears 4, 5, and 6) testing and 1538 hours of materials handling simulation (gears 1, 2, 3, and reverse). The 462 hours of high speed laboratory testing would provide the equivalent (in DAMAGE) of 1200 hours of required high speed transport operations. The 1538 hours of low speed laboratory testing would provide the equivalent (in DAMAGE) of 5608 hours of required materials handling operations. Successful completion of the 2000 hour lab test would mean that the driveline components will have completed (from a DAMAGE standpoint) an equivalent of 8000 hours of field vehicle operation.

	<u>Lab Test Hours</u>	<u>DAMAGE Acceleration Factor</u>	<u>Equivalent Field Vehicle Hours</u>
High Speed	462	2.597	1200
Materials Handling	1538	3.646	5608
Non-Damage Operations	<u>0</u>	0	<u>1192</u>
Total	2000		8000

### 3.0 DRIVELINE COMPONENT SELECTION

Deere & Company conducted a design evaluation of the SDMHE vehicle, which was targeted to meet all performance parameters specified in Solicitation DAAK70-87-R-0110. Incorporating the special requirements of SDMHE into normal design evaluation processes, Deere & Company established a Primary Selection and an Alternate Selection for driveline components. Per requirements of Contract DAAK70-87-C-0061, Deere & Company submitted its Selection of Driveline Components to the U.S. Army on 15 October 1987. Copy of this correspondence is in the Appendix (A-1 through A-5) of this report.

After formal review of the selected components, the U.S. Army (on 27 October 1987) requested that Deere & Company test the alternate choice of driveline components. This was to prevent testing of some of the same driveline components by both Deere and a second testing contractor selected by the U.S. Army. During final design evaluation of the alternate driveline components, the axle supplier (Rockwell International) indicated their need to change to a different differential ring gear reduction set. This, in turn, necessitated a request for revised gear reductions in the transmission. The transmission supplier, Twin Disc, was able to meet this request.

The finalized list of driveline components to be tested by Deere & Company was as follows:

Engine	- John Deere 6-619A
Transmission	- Twin Disc TD61-1171 Modified
Torque Converter	- Twin Disc 8FLW-1611-1
Axle (2)	- Rockwell International PRC676 (12.76 ratio)
Drive Shafts	- Borg Warner (7C size U-joints on the transmission input drive shaft and rear axle drive shaft; 8C size U-joints on the front axle drive shaft.

The John Deere 6-619A engine was an in-line six-cylinder 619 cubic inch displacement, four-stroke cycle, turbocharged and intercooled diesel. It provided 300 net horsepower at 2100 engine RPM.

### 3.0 DRIVELINE COMPONENT SELECTION (Continued)

The Twin Disc TD61-1171 Modified transmission had six forward speeds and one reverse speed. The transmission gear speed reduction ratios together with the maximum vehicle ground speed provided (with 2100 engine RPM, 12.76 axle speed reduction ratio, and 23.5 x 25 tire size) was as follows:

<u>Gear</u>	<u>Speed Reduction Ratio</u>	<u>Ground Speed (MPH)</u>
1 - Forward	4.941	5.8
1 - Reverse	3.326	8.6
2 - Forward	3.138	9.2
3 - Forward	2.114	13.6
4 - Forward	1.512	19.0
5 - Forward	0.961	30.0
6 - Forward	0.640	45.0

The Rockwell International PRC 676 (12.76 ratio) axle assembly was equipped with outboard final reduction planetary gear boxes and external air cooled disc brakes. The overall axle assembly speed reduction ratio was 12.76. The axle differential ring gear and pinion ratio was 3.544, and the final reduction planetary ratio was 3.60.

Formal approval, for these driveline components to be tested by Deere & Company, was issued by the U.S. Army by letters of 18 November 1987 and 14 December 1987. Copies of these letters are in the Appendix (A-6 through A-7) of this report.

#### 4.0 LABORATORY TEST RIG

The laboratory test rig was built to contain a complete set of selected driveline components in the basic configuration shown on Figure 2. For this high speed portion of the testing, the rear axle drive shaft was disconnected because the actual SDMHE vehicle will be equipped with a rear axle disconnect for high speed transport. This is necessary to prevent power loss and tire wear due to tire scrub interactions in gears 4-Forward through 6-Forward.

The selected engine component, preset to 312 brake horsepower at 2100 RPM, was the power source for the laboratory test. This lab engine was set to the high side of the required 300 HP to facilitate obtaining required test acceleration factors. Engine performance curve data is in the Appendix (A-8) of this report. Loading for the test unit was provided by load dynamometers which were mounted at the end of each axle, where the wheels would be attached on the field vehicle. These load dynamometers were multiple friction disc devices hydraulically actuated and hydraulically cooled. Torque at the load dynamometers was monitored through load cells connected to the moment arm of the load dynamometer. Photograph 1 shows an overall side view of the actual laboratory test rig.

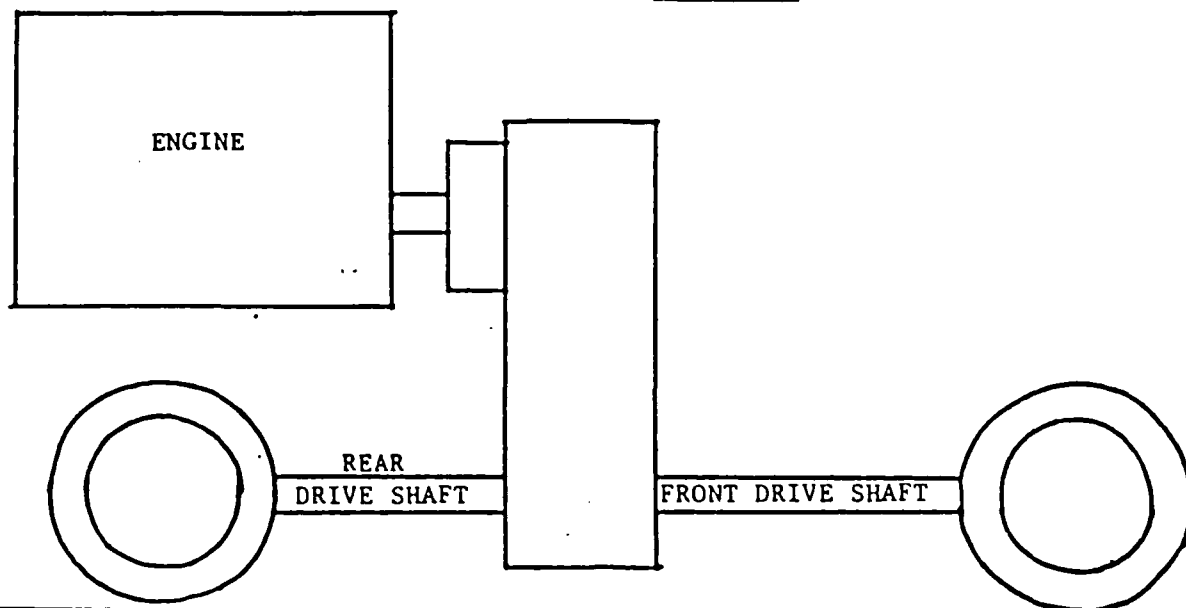
The basic control of the test rig was accomplished using a network of electro-hydraulic servo valves. Electronic torque "command" signals to the servo valves resulted in actuation of hydraulic control of the load dynamometer. The actual torque resistance provided by the load dynamometer was monitored by the load cells electronic output "feedback" signals. An analog servo amplifier, within this closed control circuit, served as the constant adjustment for keeping the actual (feedback) torque equal to the required (command) torque. The source of the torque "command" signals was an Allen Bradley programmable controller located in the control room of the laboratory test bay. Figure 3 is a schematic diagram of the hydraulic and electronic circuitry used. Photograph 2 shows the control room.

The load programs constructed for both the high speed and low speed portions of laboratory testing, and placed in the Allen Bradley controller, were step load programs. The program for high speed testing was based upon calculated values while the program for low speed (materials handling) testing was based upon results of a field histogram.



FIGURE 2: SCHEMATIC OF SDMHE POWERTRAIN IN LABORATORY TEST RIG

SIDE VIEW



TOP VIEW

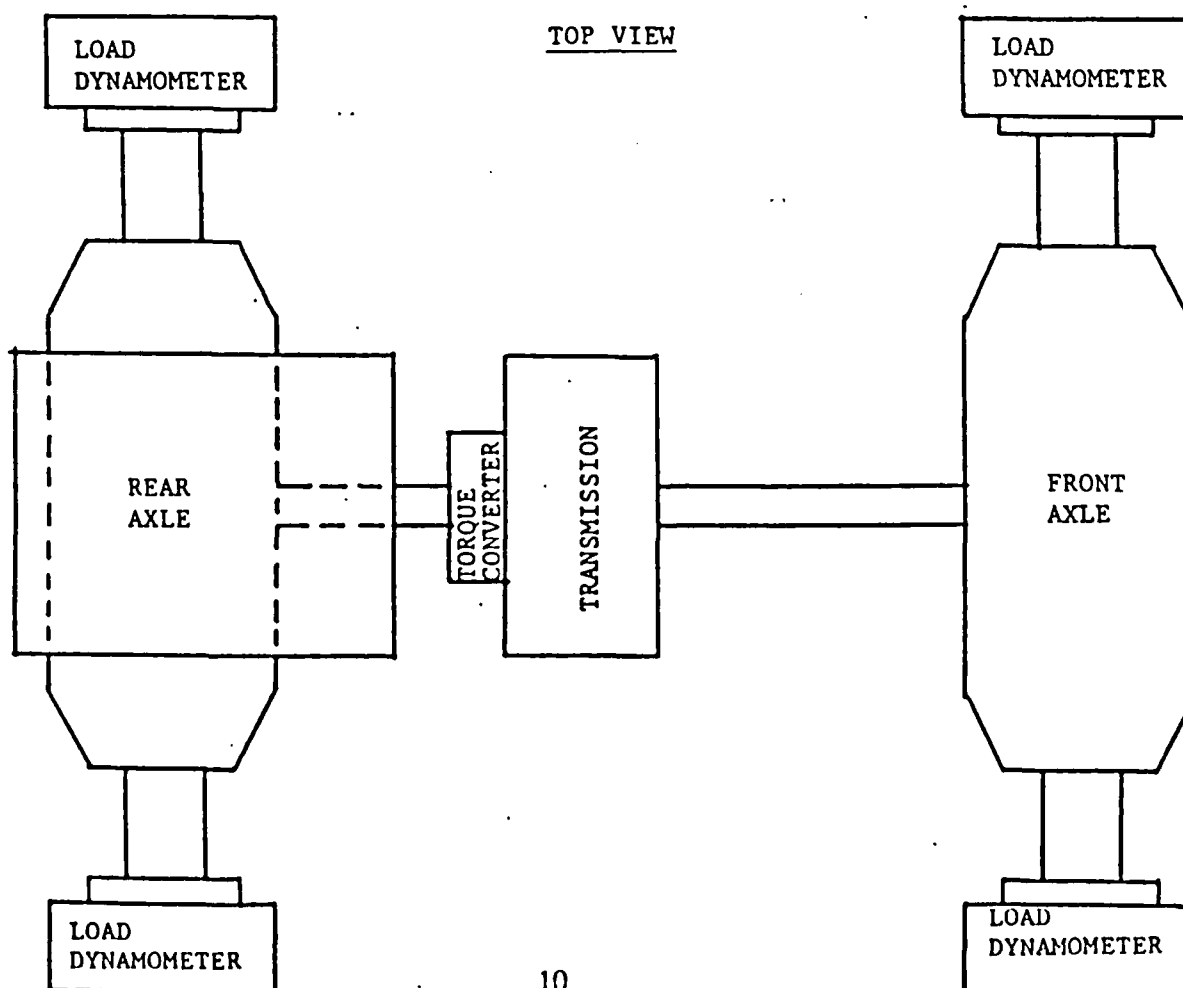
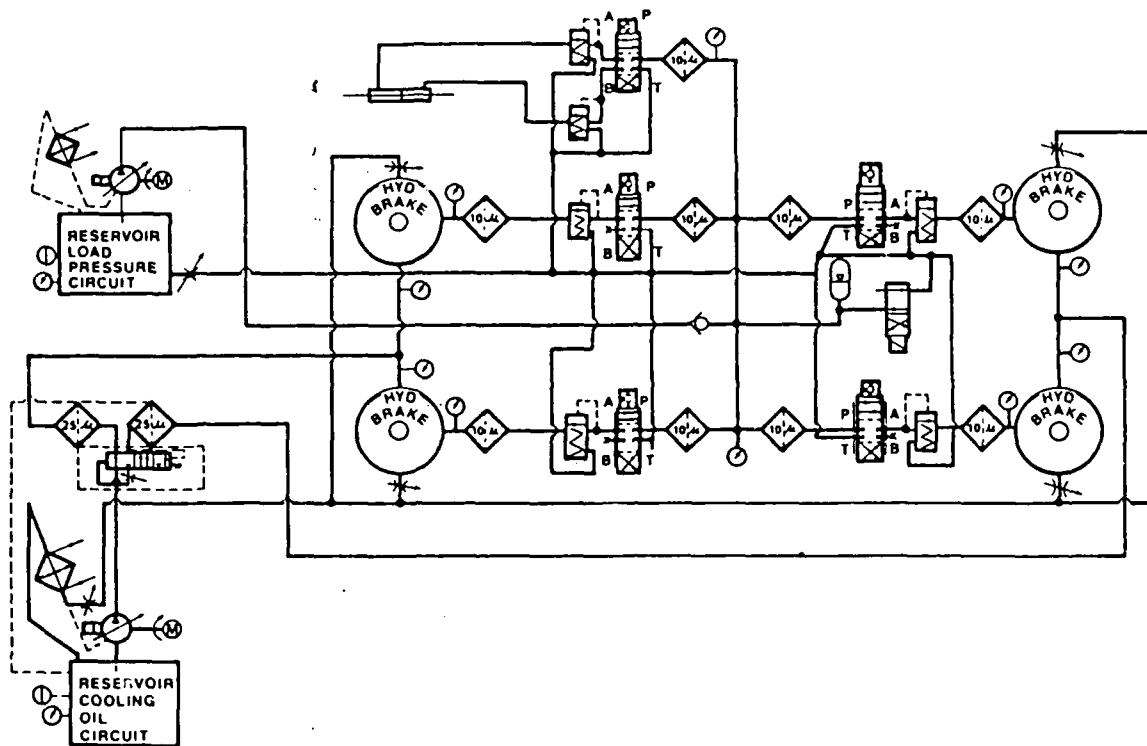
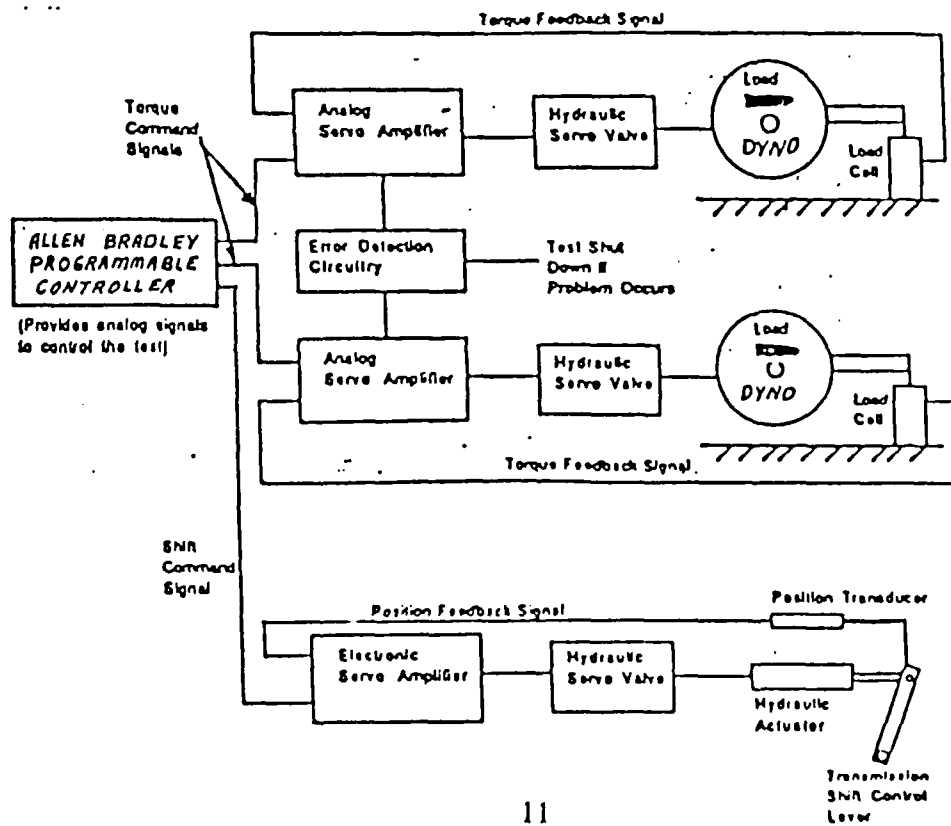


FIGURE 3  
LAB TEST RIG HYDRAULIC CIRCUITRY



LAB TEST RIG ELECTRONIC CIRCUITRY



## **5.0 HIGH SPEED LABORATORY TEST**

### **5.1 Requirement**

This test was high speed laboratory testing (Activity 11) on Figure 1 (Page 2). Per the Final Test Plan for Contract DAAK70-87-C-0061, a complete set of driveline components (engine, torque converter, transmission, front axle assembly, and three (3) drive shafts) shall be tested simultaneously in one laboratory test rig. The front axle assembly only shall transmit all loading, as the rear axle shaft assembly will be disconnected. This will simulate the actual SDMHE vehicle on which the rear axle will be disconnected during high speed transport.

This test shall consist of operating in transmission gears 4-Forward, 5-Forward, and 6-Forward. Loading, for this high speed portion of laboratory testing, shall be based upon calculated torque and RPM at the axle. Calculated torque and RPM shall be based upon the requirements of high speed transport (Operations 8, 9, 10, and 11) (Table 1 on Page 4). The test duration shall be 462 laboratory hours, and shall be equivalent in drive train DAMAGE to 1200 field vehicle hours.

Torque spikes shall be added to the test program to simulate 6-Forward to 5-Forward downshifting and 5-Forward to 4-Forward downshifting. The spikes for the 6-F to 5-F downshift will be obtained by adding a total of 2400 spikes of the proper magnitude while the test vehicle is operating in 5-Forward. The spikes for the 5-F to 4-F downshift will be obtained by adding a total of 5600 spikes of the proper magnitude while the test vehicle is operating in 4-Forward. The proper magnitude shall be determined by using Deere & Company in-house data obtained for similar procedures on commercial machines.

### **5.2 Procedure**

Meeting the requirements of high speed transport (Operations 8, 9, 10, and 11) (Table 1 on Page 4) required design performance data shown on Table 2. This design performance data was used to determine axle torques and speeds for the various operation modes of the laboratory test program requirements.

TABLE 2

## PERFORMANCE DATA

MPH	GRADE %	TRANSM. GEAR	SDMHE WEIGHT (lb)	ROLL RESIS. (%)	ROLL RESIS. (lb)	AIR RESIS. (lb)	GRADE RESIS. (lb)	TOTAL RESIS. (lb)	(1) TOTAL FRONT AXLE TORQUE (lb-in)	(2) EACH FRONT WHEEL HUB TORQUE (lb-in)	(Nm)
45	2-UP	6-F	37 000	2	740	278	740	1 758	53 232	26 616	3 008
45	2-DWN	6-F	37 000	2	740	278	-740	278	8 418	4 209	476
40	3-UP	6-F	37 000	2	740	220	1 110	2 070	62 680	31 340	3 541
40	3-DWN	6-F	37 000	2	740	220	-1 110	-150	-4 542	-2 271	-257
45	LEVEL	6-F	37 000	2	740	278	0	1 018	30 825	15 412	1 742
30	2-UP	5-F	37 000	2	740	124	740	1 604	48 569	24 285	2 744
30	2-DWN	5-F	37 000	2	740	124	-740	124	3 755	1 877	212
20	3-UP	4-F	37 000	3	1 110	55	1 110	2 275	68 887	34 444	3 892
20	3-DWN	4 F	37 000	3	1 110	55	-1 110	55	1 665	833	94

(1) Calculated using 23.5 x 25 tires (30.28 inch effective loaded radius)

(2) Each wheel hub of the front axle assembly

(3) Estimated empty weight was 37,000 lbs.

TABLE 3

FIELD BASELINE COMPOSITE OF HIGH SPEED OPERATIONS  
(DAMAGE CALCULATIONS FOR ASSUMED FIELD OPERATIONS)

(1) NO.	(2) SDMHE OPERATION SIMULATED DESCRIPTION	(3) TORQUE		(4) SPEED		(5) DAMAGE		(6) PERCENT		(7) EQUIV.		(8) TOTAL		(9) EQUIV.	
		EACH FRONT WHEEL HUB (NM)	TRANS. FRONT OUTPUT SHAFT (NM)	EACH FRONT WHEEL HUB (REV/HR)	TRANS. FRONT OUTPUT SHAFT (REV/HR)	TRANS. FRONT OUTPUT SHAFT (CY/HR)	TRANS. FRONT OUTPUT SHAFT (CY/HR)	OF TOTAL HIGH SPEED TIME	OF TOTAL HIGH SPEED TIME	TRANS. FRONT OUTPUT SHAFT (CY/HR)	TRANS. FRONT OUTPUT SHAFT (CY/HR)	LAB HIGH SPEED TIME (HR)	LAB HIGH SPEED TIME (HR)	TRANS. FRONT OUTPUT SHAFT (CYCLES)	TRANS. FRONT OUTPUT SHAFT (CYCLES)
8	45 MPH up to 2% Slope	3 088	471.5	14 986	191 224	83.98	11.17	13.3	13.3	11.17	11.17	462	462	5 160	5 160
8	45 MPH Downgrade	476	74.6	14 986	191 224	0	0	13.3	13.3	0	0	462	462	0	0
9	40 MPH up 3% Slope	3 541	555	13 321	169 977	178.59	11.97	6.7	6.7	11.97	11.97	462	462	5 528	5 528
9	40 MPH Downgrade	-257	-40.3	13 321	169 977	0	0	6.7	6.7	0	0	462	462	0	0
10	45 MPH on Level	1 742	273	14 986	191 224	4.51	.60	13.4	13.4	.60	.60	462	462	279	279
11	30 MPH up 2% Slope	2 744	430.1	9 991	127 483	34.24	3.42	10	10	3.42	3.42	462	462	1 582	1 582
11	30 MPH Downgrade	212	33.2	9 991	127 483	0	0	10	10	0	0	462	462	0	0
11	20 MPH up 3% Slope	3 892	610	6 661	84 988	148.03	19.69	13.3	13.3	19.69	19.69	462	462	9 096	9 096
11	20 MPH Downgrade	94	17.7	6 661	84 988	0	0	13.3	13.3	0	0	462	462	0	0
TOTAL EQUIVALENT DAMAGE (CYCLES) =													21 645		

(1) From Table 2.

(2) Twice column 1 divided by 12.76 (axle ratio).

(3) MPH converted to REV/HR (Used 30.28 in. effective loaded radius of tires).

(4) Column 3 multiplied by 12.76 (axle ratio).

(5) DAMAGE = (TA/TD)<sup>d</sup> (REV/HR)

TA - Column 2, TD - Used 2000 Nm, d - Used 5.35, REV/HR - Column 4

(6) Percent of total lab high speed test hours.

(7) EQUIVALENT DAMAGE = (Column 5) (Column 6)

(8) Lab test time assigned.

(9) EQUIVALENT DAMAGE (CYCLES) = (Column 7) (Column 8)

TABLE 4

### DAMAGE CALCULATIONS FOR ACTUAL LABORATORY SEQUENCE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)		
OPERATING SPEED (MPH)	TRANS. GEAR	TRANS. FRONT OUTPUT SHAFT (NM)	TRANS. FRONT OUTPUT SHAFT (REV/HR)	DAMAGE TRANS. FRONT OUTPUT SHAFT (CY/HR)	PERCENT OF LAB TEST TIME	EQUIV. DAMAGE TRANS. FRONT OUTPUT SHAFT (CY/HR)	EQUIV. DAMAGE TRANS. FRONT OUTPUT SHAFT (CYCLES)	ACCEL. FACTOR		
47.9	6-F	3 008	471.5	203 420	89.34	31.67	28.29	462	13 071	2.403
43.9	6-F	3 541	555.0	186 653	196.11	17.50	34.32	462	15 858	2.869
33.1	5-F	2 744	430.1	140 717	37.79	17.50	6.61	462	3 056	1.932
21.1	4-F	3 892	610.0	89 804	156.42	33.33	52.13	462	24 095	2.649
TOTAL EQUIVALENT DAMAGE CYCLES =							56 080	2.591		

(1) From Table 3, Column 1.

(2) From Table 3, Column 2:

(3) Actual obtained on laboratory test vehicle while maintaining torque of column 1.

$$\text{DAMAGE} = (\text{TATD})^d \text{ (REV/HR)}$$

TA - Column 2, TD - Used 2000 Nm, d- Used 5 35, REV/HR - Column 3.

(5) Percent of total lab test time.

(6) EQUIVALENT DAMAGE (CY/HR) = (Column 4) (Column 5).

(7) Total lab test time.

(8) (EQUIVALENT DAMAGE (CYCLES = (Column 6) (Column 7)).

(9) Actual Acceleration Factors of Lab Testing.

TABLE 5  
PARAMETERS USED FOR LABORATORY HIGH SPEED TESTING  
LOAD CYCLE

	Front Axle (Each Side)				
<u>Gear</u>	<u>Torque (Nm)</u>	<u>Speed (RPM)</u>	<u>Engine RPM</u>	<u>Time (Minutes)</u>	<u>Field Condition Simulated</u>
6-F	3541	244	2010	21.0	40 MPH up 3% Slope
4-F	3892	117	2265	26.5	20 MPH up 3% Slope
1-F*	(No-Load Cooling Time)			10.0	
6-F	3008	266	2195	19.0	45 MPH up 2% Slope
5-F	2744	184	2254	21.0	30 MPH up 2% Slope
6-F	3008	266	2195	19.0	45 MPH up 2% Slope
4-F	3892	117	2265	13.5	20 MPH up 3% Slope
1-F*	(No-Load Cooling Time)			<u>10.0</u>	
				120.0 At Load	
				140.0 Total	

\*After the first 16 hours of testing, it was found necessary to add these two 10 minute cooling times. This made it necessary to extend the actual time duration of this high speed test run to 536 hours, in order to obtain 462 hours at required loading.

Engine Oil Pressure	45 ± 10 PSI
Engine Oil Temperature	180 ± 10°F
Transmission Sump Oil Temperature	200 ± 10°F
Transmission Clutch Pressure	200 ± 10 PSI
Transmission Lube Pressure	10 ± 5 PSI
Front Axle Differential Sump Oil Temperature	175 ± 5°F
Front Axle RH Planetary Oil Temperature	185 ± 20°F
Front Axle LH Planetary Oil Temperature	185 ± 20°F
Engine Oil	Rock Island Fuel (CD - SAE 30)
Transmission/Torque Converter Oil	Texaco URSA Super Plus - SAE 10W
Axle Assembly Oil (All Compartments)	Sunoco GL-5 - SAE 80W90

## 5.0 HIGH SPEED LABORATORY TEST (Continued)

### 5.2 Procedure (Continued)

Table 3 established a composite, for these high speed transport operations, to be used as the calculated field vehicle baseline for laboratory high speed testing. The total equivalent DAMAGE cycles of 21,645 shown on Table 3 became the field baseline. This meant that to obtain the required acceleration factor (laboratory to field) of 2.597, the total equivalent DAMAGE cycles of the laboratory test cycle had to be 2.597 times 21,645 which is 56,212.

After the driveline test components were operational in the laboratory test rig, the actual speed versus torque relationships were obtained. Table 4 establishes a calculated laboratory load composite for meeting the required DAMAGE. This composite met the requirements of operating in gears 4-Forward, 5-Forward, and 6-Forward and for operating at ground speeds of 20, 30, 40, and 45 MPH. It also provided total equivalent DAMAGE cycles of 56,080 which was acceptably near the calculated requirement of 56,212. Table 4 was the guideline for the actual laboratory load composite.

Table 5 lists the Operating Parameters for the laboratory high speed testing. As shown, the load cycle was a two (2) hour program which was repeated constantly until 462 hours were accumulated.

Original plans were to incorporate load "spikes" into this program to simulate high magnitude, short term driveline torques obtained during high speed downshifts. It was found, however, that to get torque spikes of the magnitude required load must be applied while the driveline was unloaded. Therefore, the torque spike portion would be a separate additional test at the end of the 462 composite load cycle hour test. This separate addition consisted of:



## 5.0 HIGH SPEED LABORATORY TEST (Continued)

### 5.2 Procedure (Continued)

#### (a) Simulation of 6-Forward to 5-Forward Downshift:

With engine at full throttle, transmission in 5-Forward, and no load on front axle (rear axle still disconnected), load was applied and released to the front axle to obtain a torque "spike" of 15,000 Nm at each wheel hub. This was repeated at 8 second intervals for a 5.3 hour period, for a total of 2400 spikes. It took 2.5 seconds to go from no load to peak torque and back to no load.

#### (b) Simulation of 5-Forward to 4-Forward Downshift:

With engine at full throttle, transmission in 4-Forward, and no load on front axle (rear axle still disconnected), load was applied and released to the front axle to obtain a torque "spike" of 20,000 Nm at each wheel hub. This was repeated at 8 second intervals for a 12.4 hour period, for a total of 5600 spikes. It took 2.5 seconds to go from no load to peak torque and back to no load.

The original plans were to arrive at the proper magnitude for the torque spikes by extrapolating from data on a previous Deere commercial machine. This previous data, however, was on a scraper machine (JD762). The front axle weight transfer characteristics, during downshift, on that scraper machine were found to be completely different than on the SDMHE. This, plus the unknowns involving shift modulation characteristics required for the final SDMHE vehicle, made it virtually impossible to extrapolate torque values with any degree of accuracy. It was therefore decided to use values which are near the design converter stall torques in 5-Forward and 4-Forward, respectively, for the SDMHE.

## 5.0 HIGH SPEED LABORATORY TEST (Continued)

### 5.3 Results

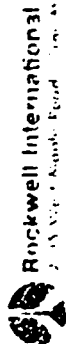
The test engine, torque converter, transmission, and drive shafts all performed acceptably for the duration of the 462 hour high speed test. Problems were encountered with the front axle assembly relating to excessive oil temperatures and nylon material bushings.

After 16 of the scheduled 462 hours of high speed testing, a failure occurred in the LH planetary of the front axle assembly. The failure was a "wipe out" of the nylon material bushings which are the bearing surfaces between the I.D. of the planetary pinions and the planetary pinion shafts. See Photograph 3.

The reason for the failure was excessive oil temperature (275°F) in the planetary compartment. Although there were no seals separating oil in the planetary compartment from that in the differential ring gear compartment, the oil flow passages were found to be inadequate for providing any equalizing of oil temperatures between compartments. While the test stand was, at that time, maintaining oil temperature in the differential ring gear compartment at 160°F via external oil cooler, the planetary compartment oil temperature reached approximately 275°F. The axle supplier (Rockwell International) has indicated that the nylon material begins softening at 250°F.

The planetary compartment oil temperature approximation of 275°F was based upon results of oil temperature testing conducted after the left-hand planetary was rebuilt. Thermocouples were installed in the planetary sump. It was necessary to stop planetary hub rotation (place transmission in neutral) to take each oil temperature reading. A time versus planetary oil temperature curve was developed from this test. The test was stopped when planetary oil temperature reached 220°F. By extrapolating the oil temperature curve obtained, it was estimated that the planetary oil temperature would stabilize at 275°F.

The RH planetary of the front axle was also disassembled for inspection. Although the nylon bushings on this side were still intact, it was decided to install new ones just in case they had also seen excessive temperatures on the RH side. See Photograph 4.



Rockwell International  
21400 North 10th Street, Milwaukee, WI 53222

# BILL OF MATERIAL

WR-9340

S-620-0

DESCRIPTION: SHAFT & HUB GROUP-PLANET, FINAL DRIVE-3.6-1 RED.-83.38 FLG. TO FLG.

PRECEDENCE: PRC-676-N202 & 203

REVISIONS: SEE SUB-ASSEMBLY'S BILL OF MATERIAL FOR REVISIONS  
ASSEMBLY: SEE SUB-ASSEMBLY'S BILL OF MATERIAL FOR REVISIONS

DATE: 7 DEC 87

1

1

CHANGE	SUB-ASSEMBLY	PART NO.	NAME	NO. REQD.	SUB-ASSEMBLY	PART NO.	NAME	NO. REQD.	CHANGE
		NL-112-1	NUT-SPINDLE TO HSG.	28		1844-D-574	PROTECTOR-WHEEL STUD	24	
		S-2812-1	CAPSCREW-PLANET, SPIDER TO HUB	60		1850-T-150	PLUG-PLANET, OIL LEVEL	2	
		S-11224-1	CAPSCREW-SPINDLE TO HSG.	28		1854-W-257	SNAP RING-AXLE SHAFT RETAINER	2	
		52400	CONE-HUB INNER BRG.	2		1890-S-1137	THRUST BUTTON-RING GEAR	6	
		52618	CUP-HUB INNER BRG.	2		2297-T-4570	THRUST BUTTON-AXLE SHAFT	2	
		68462	CONE-HUB OUTER BRG.	2					
		68712	CUP-HUB OUTER BRG.	2					
		10-X-1093	SCREW-WHEEL BRG. NUT LOCK	4		A* 3198-V-126	SHAFT-PLANET, PINION	6	
		20-X-262	STUD-WHEEL	24		3202-C-8521	SHAFT-AXLE-SHORT	1	
		26-X-237	SETSCREW-PLANET, PINION SHAFT	3-6(LH ONLY)		3202-T-8522	SHAFT-AXLE-LONG	1	
		A* 333-M-3133	HUB-WHEEL	2		3204-G-33	HUB-PLANET, RING GEAR	2	
		* 1199-Q-2981	LIQUID GASKET-SPIDER TO HUB	2oz.		3213-S-1319	SPINDLE-WHEEL BRG.	2	
		* 1199-Q-2981	LIQUID GASKET-AXLE SHFT, THR. BUTN.	2oz.					
		* 1199-Q-2981	LIQUID GASKET-SPINDLE TO HSG.	2oz.		A1A* 3298-N-14	SPIDER-PLANET, GEAR	1-2(LH ONLY)	
		* 1199-Q-2981	LQ. GASKET-RING GEAR THRUST BUTN.	2oz.		3789-T-384	"O" RING-PLANET, PINION SHAFT	6	
		A* 1205-S-1631	OIL SEAL-HUB BRG. RETAINER	2		3892-G-1541	GEAR-PLANET, SUN (20T)	1-2(LH ONLY)	
		1220-D-56	LOCK-WHEEL BRG. NUT	2		3892-H-1542	PINION-PLANET, (16T)	3-6(LH ONLY)	
		1227-G-995	NUT-WHEEL BRG.	2		3892-N-4070	GEAR-PLANET, RING (52T)	2	
		1229-V-1504	WASHER-SPINDLE TO HSG.	28					
		1229-C-1511	WASHER-SPIDER TO HUB CAPSCREW	60					
		1229-V-3116	WASHER-PLANET, SUN GEAR	2					
		1329-F-703	WASHER-PLANET, PINION THRUST-OUTER	2					
		1829-X-856	WASHER-PLANET, PINION THRUST-INNER	2					

Table 6

## 5.0 HIGH SPEED LABORATORY TEST (Continued)

### 5.3 Results (Continued)

Rockwell International provided a new replacement planetary assembly for the LH side which included the planet gear spider, planet pinions, sun pinion, and planet pinion shafts. New planet pinion shafts were provided for the RH side (Photograph 5). The tapered roller bearings were also replaced on both sides as a precaution. The parts replaced are those "circled" on Table 6. Photographs 6 through 10 show other heat distressed parts, which were replaced.

To continue laboratory testing without overheating the front axle planetary oil, it was necessary to:

- (a) Position portable air conditioning units to blow cool air across both planetaries of the front axle assembly. These units maintained ambient temperatures of 65°-75°F at the outer surfaces of the planetary housings.
- (b) Add two 10 minute cooling periods to the test cycle. These are identified on Table 5 (Page 16). Planetary oil temperature decreased at the rate of 2°F per minute during the cooling period.

With these revisions in planetary cooling, the planetary oil temperature held at 180-200°F for the remainder of the high speed testing. The differential ring gear compartment oil temperature held at 170-180°F. No further problems were encountered with the nylon bushings.

No significant changes occurred with engine oil pressure, oil temperature, oil consumption, or engine power output during the 462 hours of high speed testing. Maintenance of engine power was based upon no depreciation in engine RPM or axle RPM while maintaining the specified axle torque levels (Table 5 on Page 16). Engine oil consumption rate was 65-70 hours per quart, which is quite acceptable.

## **5.0 HIGH SPEED LABORATORY TEST (Continued)**

### **5.3 Results (Continued)**

No significant changes occurred with transmission clutch pressures, lube pressure, or oil temperature during the 462 hours of high speed testing. That indicated no depreciation in sealing element effectiveness within the transmission. Due to an original assembly omission, the gasket specified between the engine flywheel housing and the torque converter housing was missing. This resulted in external leakage of transmission/torque converter circuit oil at the rate of 1 quart per 24 test hours. Rather than disassemble the test rig to install this gasket, the required make-up oil was added.

## **6.0 FIELD TORQUE HISTORY (HISTOGRAM)**

### **6.1 Requirement**

The histogram included vehicle preparation (Activity 10) and conducting the histogram (Activity 12), as shown on Figure 1 (Page 2). Per the Final Test Plan for Contract DAAK70-87-C-0061, a field histogram shall be conducted to obtain actual driveline torque and speed data while operating a SDMHE prototype vehicle through the various required materials handling field operations. This data shall then be used to construct a laboratory test program to test the selected driveline components during SDHME low speed materials handling operations. Histogram data shall be collected while operating the field vehicle per the requirements of material stockpiling (Operations 1, 2, and 3), material transport (Operations 4, 5, 6, and 7), and transporting material at 2 MPH up a 45 percent slope (Operation 12) as shown on Table 1 (Page 4).

### **6.2 Procedure**

An obsolete prototype 644E Wheel Loader, which was scheduled for scrapping at Deere & Company, served as the basic envelope into which a complete set of the selected driveline components were installed. This set of driveline components was the second set purchased for the overall program, and was identical to the set installed in the laboratory test rig (see 5.1 on Page 12), except for the differential in the axle assemblies. The two axle assemblies installed in this field histogram vehicle were equipped with standard differentials. The two axle assemblies in the laboratory test rig were equipped with no-spin differentials which was a necessity for proper load control in the laboratory.

Installation of the test components within the machine envelope required repositioning of all driveline component attachment points. An experimental cradle assembly was designed, built, and installed on the rear axle assembly to provide the required rear axle oscillation capability on this field vehicle. The gear shifting control console for the transmission (equipped with electronic solenoid shifting) was mounted in the vehicle cab. Activation of the vehicle service brakes (brakes were axle mounted, outboard air cooled, hydraulically activated disc type) was accomplished by utilizing the existing brake hydraulic circuit on the machine.

## **6.0 FIELD TORQUE HISTORY (HISTOGRAM) (Continued)**

### **6.2 Procedure (Continued)**

The materials handling forks installed on this field vehicle were an obsolete version of a fork carriage option available for the Deere 644E Wheel Loader. Installation required revision of the pivot pins and bores of the vehicle loader frame and boom. The vehicle was equipped with 23.5 x 25 tires which were available from used parts storage at Deere. Counterweights were designed, fabricated, and mounted on the rear of the vehicle engine frame for proper weight distribution. The 10K load requirement on the forks was provided by using a specifically designed 10K package for forks, which was already available at Deere.

The field vehicle was instrumented to simultaneously measure and record engine RPM, transmission input shaft torque and RPM, front axle input shaft torque and RPM, rear axle input shaft torque and RPM, and gear selector position. This data was collected using telemetry equipment and Deere's mobile instrumentation van. The operations performed were as follows:

Operation 1 was Material Stockpiling on concrete surface. It was estimated (Table 1 on Page 4) that this operation mode will make up 10 percent of the SDMHE field life. The proposed duty cycle for field torque history purposes involved moving a pallet, loaded to 10,000 lbs., around the perimeter of a 100 ft. diameter circle as shown on Figure 4. Starting at point 1 (Figure 4), pick up the load and move it to point 3. After placing the load at point 3, back up into the center of the circle. Then proceed in forward gear back to point 3, pick up the load and move it to point 5. After placing the load at point 5, back up into the center of the circle. Then proceed in forward back to point 5, pick up the load and move it to point 2. Continue this sequence for moving the load around circle. Forward operation was in second gear.

Operation 2 was Materials Handling on unimproved surface (noncompacted dirt). It was estimated (Table 1 on Page 4) that this operation mode will make up 20 percent of the SDMHE field life. For the field torque history, the proposed duty cycle and cycle rate were the same as for Operation 1. Operation was in first gear.

## **6.0 FIELD TORQUE HISTORY (HISTOGRAM) (Continued)**

### **6.2 Procedure (Continued)**

Operation 3 was Materials Handling on beach surface (loose sand). It was estimated (Table 1 on Page 4) that this operation mode will make up 5 percent of the SDMHE field life. For the field torque history, the proposed duty cycle and cycle rate were the same as for Operation 1. Operation was in first gear.

Operation 4 was Material Transport on improved surface. It was assumed (Table 1 on Page 4) that this operation mode will make up 10 percent of the SDMHE field life. For the field torque history, the proposed duty cycle was to pick up a pallet loaded to 10,000 lbs; reverse while turning 180 degrees; transport the load forward approximately 250 ft.; deposit pallet on ground; reverse approximately 15 ft.; forward to pick up the pallet and repeat the entire procedure. Forward operations were in second and third gears.

Operation 5 was Material Transport on unimproved surface (noncompacted dirt). It was estimated (Table 1 on Page 4) that this operation mode will make up 15 percent of the SDMHE field life. Forward operations were in first and second gears.

Operation 6 was Material Transport over crossties. It was estimated (Table 1 on Page 4) that this operation mode will make up 5 percent of the SDMHE field life. For the field torque history, the proposed duty cycle was to travel forward passing over four crossties (situated as shown in Figure 4). Immediately after traversing the last crosstie, reverse direction and travel forward again passing over four crossties. Immediately after traversing the last crosstie, reverse direction and repeat the cycle. Forward operation was in first gear.

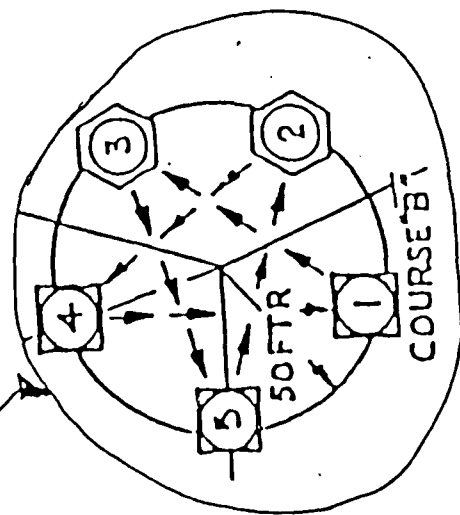
Operation 7 was Material Transport through potholes. It was estimated (Table 1 on Page 4) that this operation mode will make up 5 percent of the SDMHE field life. For the field torque history, the proposed duty cycle was like that for Operation 6, except that the four crossties will be replaced with three potholes. Forward operation was in first gear.



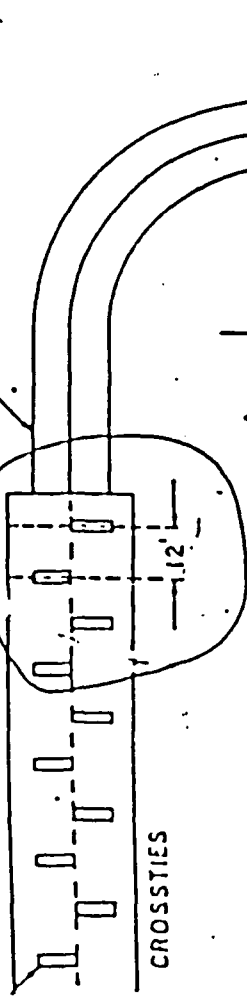
Figure 4

four crossies (for Operation 6)

Course for Operation 1

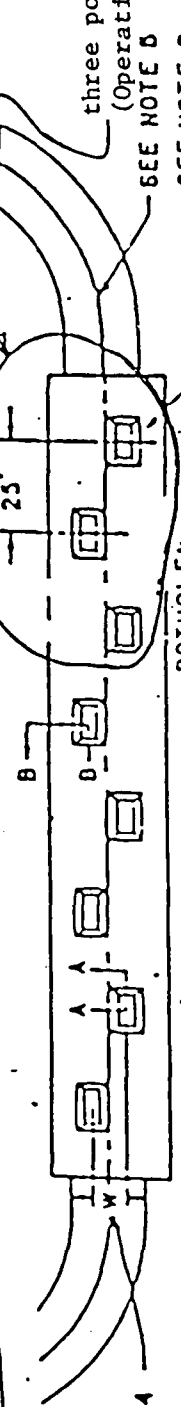


SEE NOTE 3



CROSSIES

DURABILITY TEST TRACK



three potholes  
(Operation 7)

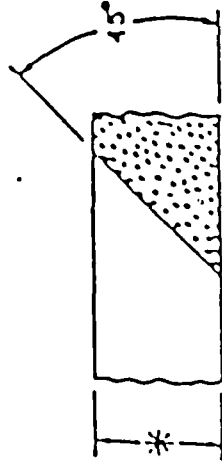
SEE NOTE 4

POTHOLES

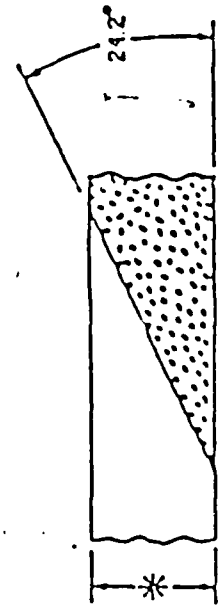
NOTES:

1. ELEVEN CROSSIES, 6' LONG, ANCHORED TO PREVENT MOVEMENT. CROSSIES SHALL BE 2" HIGH, 4" WIDE FOR FORKLIFTS UNDER 6000 LB CAPACITY, 6" BY 6" FOR FORKLIFTS OF 6000 LB. AND OVER CAPACITY.
2. EIGHT CONCRETE POTHoles 6' WIDE AND 8' LONG SUNK FLUSH WITH GROUND LEVEL.
3. STABILIZED SURFACE 15' WIDE MINIMUM, EACH END OF COURSE.
4. W WILL BE THE APPROXIMATE TREAD OF THE VEHICLE.
5. DISTANCE AROUND COURSE AT CENTERLINE IS 760 ± 30 FEET. THIS COURSE MAY BE CONSTRUCTED WITH CROSSIE AND POTHOLE SECTIONS IN LINE, END TO END WITH TURN AROUND AT EACH END, PROVIDED TOTAL DISTANCE TRAVELLED IN ONE CYCLE IS 750 ± 30 FEET.

FORKLIFT CAPACITY	POTHOLE DEPTH (")
UNDER 6000 LBS	4 INCHES
6000 LBS AND OVER	12 INCHES



SECTION A-A



SECTION B-B

## **6.0 FIELD TORQUE HISTORY (HISTOGRAM) (Continued)**

### **6.2 Procedure (Continued)**

Operation 12 was traveling at 2 MPH up a 45% grade unimproved surface, with 10,000 lb. load. It was estimated (Table 1 on Page 4) that this operation will make up 0.1 percent of the SDMHE field life. Operation was in first gear.

### **6.3 Results**

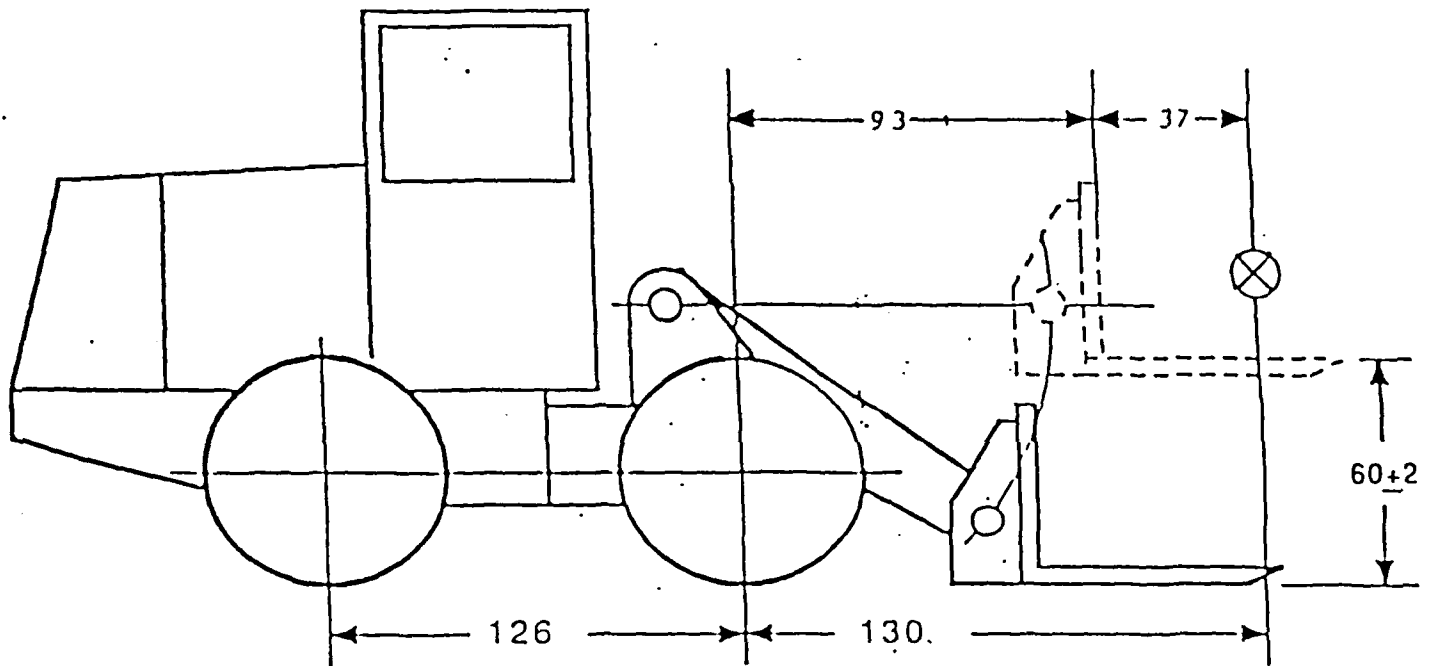
The actual field SDMHE vehicle constructed for the histogram is shown in Photograph 11. The vehicle was equipped with a complete set of the selected driveline components listed on Page 7. Rear counterweight was installed to provide weight distribution and tipping loads consistent with military 10K forklift truck specifications. The pertinent dimensions relating to weight distribution, as well as the unloaded and loaded vehicle weights, are shown on Figure 5.

Material stockpiling (Operations 1 and 2), and material transport (Operations 4, 5, 6, and 7), as described in the Procedure Section (Page 23), were conducted at prepared sites located on the X-18 Proving Grounds at the John Deere Dubuque Works. Operation 3 was conducted on a hill of beach type sand, located adjacent to the south end of the Dubuque Works factory. Transporting material at 2 MPH up a 45% slope (Operation 12) was conducted in a stone quarry, located adjacent to the north side of the Dubuque Works property. A 45% slope ramp, built at this site for a prior military vehicle evaluation, was used.

The computer tabulated data as collected for the front axle input shaft and the rear axle input shaft during material stockpiling (Operations 1, 2, and 3), material transport (Operations 4, 5, 6, and 7), and transporting material at 2 MPH up a 45% slope (Operation 12), as listed on Table 1 (Page 4) is included in the Appendix (Pages A-9 through A-29). The key data contained on the charts in the Appendix (Pages A-9 through A-29) is the DAMAGE value tabulated in the bottom column of each chart. This DAMAGE value is in DAMAGE cycles/hour.

FIGURE 5

SDMHE Dimensions



Wheelbase	126 inches
Unloaded: (No weight on forks, fork at at 60 inch vertical height)	
Total Vehicle Weight	36,376 lbs.
Front Axle Weight	17,483 lbs.
Rear Axle Weight	18,893 lbs.
Loaded: (C.G. of 10,000 lb. weight is 37 inches forward of the fork heel, fork at 60 inch vertical height)	
Total Vehicle Weight	46,376 lbs.
Front Axle Weight	37,800 lbs.
Rear Axle Weight	8,576 lbs.

## **6.0 FIELD TORQUE HISTORY (HISTOGRAM) (Continued)**

### **6.3 Results (Continued)**

To exemplify how the data from the Appendix charts (Pages A-9 through A-29) is used to establish the laboratory test DAMAGE baseline refer to the Appendix (Pages A-13 and A-14). Pages A-13 and A-14 are computerized tabulations of the data collected at the front axle input shaft during material stockpiling on a beach surface (Operation 3) as listed on Table 1 (Page 4). The vertical column headed 1F compiles the rev/hr of this shaft at each torque level shown in the vertical column headed Mean Torque Level. DAMAGE is also continually calculated. The total DAMAGE (157,385) at the front axle shaft during 1-Forward is at the bottom of the column headed 1F in Appendix (Page A-14). This DAMAGE value (157,385) then becomes input for Column (2) on Table 7. This procedure is repeated for each gear used in each field operation to completely compile Column (2) on Table 7.

Table 7 is a tabulation of the field DAMAGE data by operation and gear selection. The percent of time in each operation, as required on Table 1 (Page 4), is applied to obtain an equivalent DAMAGE in cycles/hour. The total equivalent DAMAGE is then obtained -- 8234.6 cycles/hour at front axle input shaft, and 455.1 cycles/hour at rear axle input shaft. These two values were the field baseline for setting up the laboratory test program. Operations 8, 9, 10, and 11 shown on Table 1 (Page 4) are not in Table 7, because these high speed transport operations were not run during the field histogram. This was explained in the overall test procedure (Page 5).

As shown in Column 6 of Table 7, 94 percent of the total equivalent DAMAGE compiled for all operations of this field histogram occurred during Operation 3. Operation 3 was materials handling on beach surface. The DAMAGE accumulation during this operation was comparatively high during a segment when all four vehicle tires became mired down in the sand to a depth of approximately 19 inches. In this situation, the vehicle was not yet "high centered" and was able to progress and get out of the mired down situation in the reverse direction. This miring down in the sand is something that can and does occur in actual beach operations and must be part of the histogram. The miring down in the sand

TABLE 7

TABULATION OF DAMAGE AND GEAR SELECTION FOR FIELD  
BASELINE COMPOSITE OF MATERIALS HANDLING OPERATIONS

SDMHE OPERATION TABLE 1 PAGE 4	GEAR SELECTION	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		TORQUE MAX. AT FRONT AXLE INPUT SHAFT (NM)	DAMAGE AT FRONT AXLE INPUT SHAFT (CY/HR)	DAMAGE AT REAR AXLE INPUT SHAFT (CY/HR)	TORQUE MAX. AT REAR AXLE INPUT SHAFT (NM)	PERCENT OF TOTAL MATERIALS HANDLING TIME (EACH GEAR)	EQUIV. DAMAGE AT FRONT AXLE INPUT SHAFT (CY/HR)	EQUIV. DAMAGE AT REAR AXLE INPUT SHAFT (CY/HR)
Operation 1	2-Forward	3 200	269	255	2 500	7.14	19.2	18.2
	1-Reverse	3 100	248	280	2 000	7.14	17.7	20.0
Operation 2	1-Forward	2 900	181	52	2 500	14.29	25.9	7.4
	1-Reverse	2 500	203	17	2 000	14.29	29.0	2.4
Operation 3	1-Forward	5 600	157 385	5 104	3 100	3.57	5 617.0	182.2
	1-Reverse	7 300	59 545	24	2 300	3.57	2 126.0	0.9
Operation 4	2-Forward	2 900	385	157	2 200	5.71	22.0	9.0
	3-Forward	2 900	676	323	1 900	5.71	38.6	18.4
	1-Reverse	2 800	150	87	1 700	2.87	4.3	2.5
Operation 5	1-Forward	2 000	313	223	2 200	8.57	26.8	19.1
	2-Forward	2 300	143	106	2 200	8.57	12.3	9.1
	1-Reverse	1 700	614	77	2 200	4.29	26.3	3.3
Operation 6	1-Forward	2 600	350	273	2 800	6.42	22.5	17.5
	1-Reverse	2 500	319	162	2 500	0.72	2.3	1.2
Operation 7	1-Forward	3 200	1 574	596	2 800	6.42	101.1	38.3
	1-Reverse	2 500	78	19	500	0.59	0.5	0.1
Operation 12	1-Forward	3 500	110 100	81 132	3 400	0.13	143.1	105.5
		TOTAL EQUIVALENT DAMAGE (FORWARD) =					6 028.5	424.7
		(REVERSE) =					2 206.1	30.4
		(TOTAL) =					8 234.6	455.1

(1), (2), (3), and (4)

(5)

From Data Sheets (Appendix A-8 Through A-28)

Requirement of Table 1 on Page 4

(6)

Equivalent DAMAGE (CY/HR) = (Column 2) (Column 5)

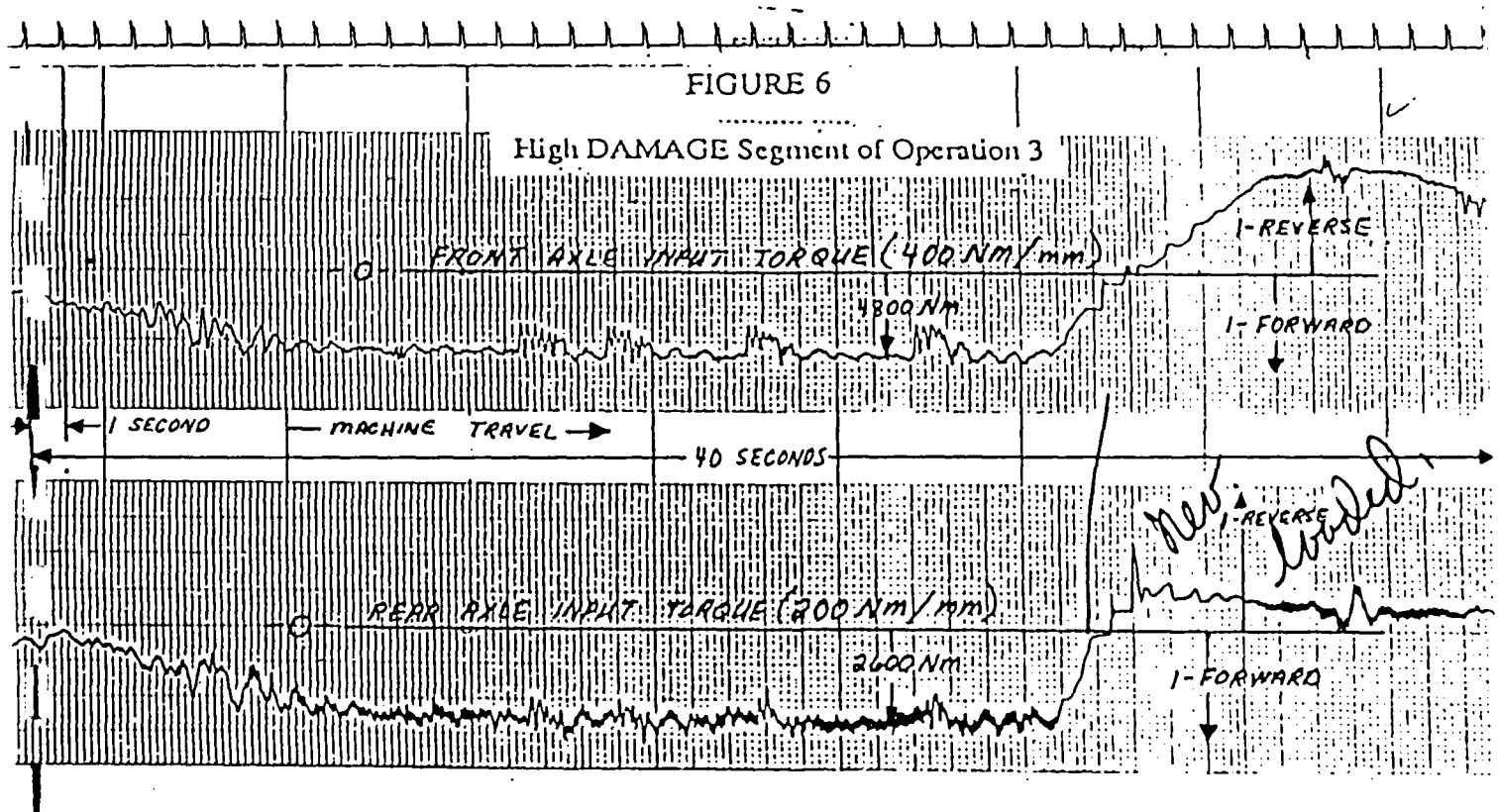
(7)

Equivalent DAMAGE (CY/HR) = (Column 3) (Column 5)

## 6.0 FIELD TORQUE HISTORY (HISTOGRAM) (Continued)

### 6.3 Results (Continued)

and back out was a 40 second segment of the 353 second data collection time used to compile the histogram for Operation 3. Figure 6 shows the recording made by pen recorder of front axle input shaft torque and rear axle input shaft torque during this 40 second segment.



## **7.0 LOW SPEED LABORATORY TEST**

### **7.1 Requirement**

This test was low speed testing (Activity 14) on Figure 1 (Page 2). Per the Final Test Plan for Contract DAAK70-87-C-0061, a complete set of driveline components (engine, torque converter, transmission, front axle assembly, and three (3) drive shafts) shall be tested simultaneously in one test rig. The set of driveline components to be tested during low speed testing (Activity 14) shall be the same physical parts which previously accumulated 462 laboratory hours of high speed testing (Activity 11). These components shall be undisturbed since completing Activity 11. For this low speed testing, which simulates materials handling operations with the SDMHE vehicle, both the front and rear axle assemblies shall transmit loading.

This test shall consist of operating in transmission gears 1-Forward, 2-Forward, 3-Forward, and 1-Reverse. Loading, for this low speed portion of laboratory testing, shall be based upon torque and DAMAGE data acquired during the field histogram (Section 6.0, Page 23). The test duration shall be 1538 laboratory hours, and shall be equivalent in drive train DAMAGE to 5608 field vehicle hours.

### **7.2 Procedure**

After completion of the high speed laboratory test (Activity 11) on Figure 1 (Page 2), the rear axle drive shaft was installed on the laboratory test rig, so that power could be transmitted by both front and rear axle assemblies during the low speed testing (Activity 14). The derated load dynamometers, which were used on each wheel hub of the front axle during high speed testing (Activity 11) were switched to the rear axle for low speed testing (Activity 14). Full rated load dynamometers were installed on the front axle for low speed testing (Activity 14).

Table 7 (Page 30) established a composite duty cycle for the low speed materials handling operations, to be used as the field vehicle baseline for laboratory low speed testing. This composite duty cycle was based upon actual load data collected during the field histogram. The total equivalent DAMAGE (cycles/hour) of 8234.6 for the front axle input and 455.1

## 7.0 LOW SPEED LABORATORY TEST (Continued)

### 7.2 Procedure (Continued)

for the rear axle input shown on Table 7 (Page 30) became the field baseline. This means that to obtain the required acceleration factor (laboratory to field) of 3.646, the total equivalent DAMAGE (cycles/hour) of the laboratory test cycle must be 3.646 times 8234.6 which is 30,023 for the front axle input shaft, and 3.646 times 455.1 which is 1659 for the rear axle input shaft.

With the laboratory test rig operational for low speed testing (Activity 14), the actual speed versus torque relationships were obtained. Table 8 established a laboratory composite duty cycle load for meeting the required DAMAGE. This composite met the requirement of operating in gears 1-Forward, 2-Forward, 3-Forward, and 1-Reverse. It also provided total equivalent DAMAGE (cycles/hour) of 29,927 (front axle) and 1723 (rear axle) which was acceptably near the requirements of 30,023 and 1659 respectively. Table 8 was the guideline for the actual laboratory load composite duty cycle.

Table 9 lists the operating parameters for laboratory low speed testing. As shown, the load cycle was a six (6) minute program which was repeated constantly.

### 7.3 Results

No significant changes occurred with engine oil pressure, oil temperature, oil consumption, or engine power output during the 865 hours of low speed testing. Maintenance of engine power was based upon no depreciation in engine RPM or axle RPM while maintaining the specified axle torque levels (Table 9). Engine oil consumption rate remained at 65-70 hours per quart, which is quite acceptable.

No significant changes occurred with transmission clutch pressures, lube pressure, or oil temperature during the 865 hours of low speed testing. That indicated no depreciation in sealing element effectiveness within the transmission. Due to an original assembly omission, the gasket specified between the engine flywheel housing and the torque



TABLE 8

## DAMAGE TABULATION FOR LABORATORY LOW SPEED TESTING

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)			
TRANS. GEAR	TORQUE LEVEL	TRANSMISSION OUTPUT SPEED (RPM)	TORQUE AT FRONT AXLE INPUT (NM)	TORQUE AT REAR AXLE INPUT (NM)	DAMAGE AT FRONT AXLE INPUT (CY/HR)	DAMAGE AT REAR AXLE INPUT (CY/HR)	PERCENT OF LAB TEST TIME	EQUIV. DAMAGE AT FRONT AXLE INPUT (CY/HR)	EQUIV. DAMAGE AT REAR AXLE INPUT (CY/HR)	SECONDS OF EACH 6-MIN. SEGMENT	
1-F	1	440	26413	1803	1442	15144	4590	30.83	4669	1415	111
	2	434	26030	3762	—	764369	—	2.22	16969	—	8
2-F	1	694	41649	1003	940	1038	735	18.89	197	139	68
3-F	1	977	58645	940	862	1035	650	13.06	135	85	47
1-R	1	658	39505	940	784	697	263	31.94	223	84	115
	2	293	17609	3292	—	253109	—	3.06	7734	—	11
<hr/>											
TOTAL EQUIVALANT DAMAGE											
(FORWARD) = 21970 (3.64) 1639 (3.86)											
(REVERSE) = 7957 (3.61) 84 (2.76)											
(TOTAL) = 29927 (3.64) 1723 (3.79)											

\*Acceleration Factor (Lab Damage/Field Damage) - Field Damage Values are on Table 7.

- (1) Actual values obtained on lab test rig, at torque levels chosen in Columns (2) and (3).  
 (2) (3) Torque levels selected based upon field histogram results.

(4) (5) DAMAGE = (TA/TD)d (REV/HR)

TA - Column 2 and 3; TD - Used 2000 Nm; d - Used 5.35; REV/HR - Column 1

(6) Per Table 1 on Page 4.

(7) (Column 4) (Column 6)

(8) (Column 5) (Column 6)

(9) (Column 6) (360 seconds)

TABLE 9  
PARAMETERS USED FOR LABORATORY LOW SPEED TESTING  
LOAD CYCLE

<u>Gear</u>	<u>Front Axle</u> <u>(Each Side)</u>		<u>Rear Axle</u> <u>(Each Side)</u>		<u>Engine</u> <u>RPM</u>	<u>Time</u> <u>(Seconds)</u>
	<u>Torque</u> <u>(Nm)</u>	<u>Speed</u> <u>(RPM)</u>	<u>Torque</u> <u>(Nm)</u>	<u>Speed</u> <u>(RPM)</u>		
1-F	11500	34.5	9200	34.5	2177	111
1-F	24000	34.0	0	34.0	2150	8
2-F	6400	54.4	6000	54.4	2178	68
3-F	6000	76.6	5500	76.6	2058	47
2-F	Shift Through at No Load					
1-F	Shift Through at No Load					
1-R	6000	51.6	5000	51.6	2195	115
1-R	21000	23.0	0	23.0	1550	<u>11</u>
						360

Engine Oil Pressure	45 ± 10 PSI
Engine Coolant Temperature	180 ± 10°F
Transmission Sump Oil Temperature	200 ± 10°F
Transmission Clutch Pressure	200 ± 10 PSI
Transmission Lube Pressure (@ End Cap)	10 ± 5 PSI
Front Axle Differential Sump Oil Temperature	175 ± 5°F
Front Axle RH Planetary Oil Temperature	185 ± 20°F
Front Axle LH Planetary Oil Temperature	185 ± 20°F
Rear Axle Differential Sump Oil Temperature	175 ± 5°F
Rear Axle RH Planetary Oil Temperature	185 ± 20°F
Rear Axle LH Planetary Oil Temperature	185 ± 20°F
Engine Oil	Rock Island (CD - SAE 30)
Transmission/Torque Converter Oil	Texaco URSA Super Plus - SAE 10W
Axle Assembly Oil (All Compartments)	Suncco GL-5 - SAE 80W90

## **7.0 LOW SPEED LABORATORY TEST (Continued)**

### **7.3 Results (Cont'd)**

converter housing was missing. This resulted in external leakage of transmission/torque converter circuit oil at the approximate rate of 1 quart per 24 test hours. Rather than disassemble the test rig to install this gasket, the required make-up oil was added.

The low speed laboratory test was terminated per telephone agreement of 16 February 1989 with David Krawchuk of the U.S. Army. This termination was the result of the second of two similar failures of the spiral bevel ring gear in the differential of the front axle assembly. Test termination occurred with 865 of the scheduled 1538 low speed laboratory test hours (Activity 14) complete.

The test engine, torque converter, transmission, and drive shafts all performed acceptably for the duration of the 865 low speed laboratory test hours completed. Four (4) separate downtime periods occurred during that 865 hours of laboratory testing. All four (4) involved the front axle assembly.

#### **7.3.1 Downtime Period at 0 Hours of the Scheduled 1538 Hours**

Prior to starting the low speed laboratory testing run, it was necessary to conduct test runs to record the actual wheel hub output torque to wheel hub RPM relationship in each of the gears to be used. This was necessary to determine the time required at a given load level in a given gear to obtain the required DAMAGE factor.

While conducting this preparatory testing in 1-Forward, a low cycle or "one shot" failure of the RH axle shaft of the front axle assembly was experienced (see Photograph 12). Subsequent analysis of the laboratory test rig electronic circuitry revealed a faulty component in the load circuitry of the RH load dynamometer. This electronic component provided accurate RH torque monitoring up to 21,000 Nm at the wheel hub. Above 21,000 Nm, however, the monitored value became much less than the actual torque value. As a result, while the RH torque monitor indicated 21,500 Nm wheel hub torque

## 7.0 LOW SPEED LABORATORY TEST (Continued)

### 7.3.1 Downtime Period at 0 Hours of the Scheduled 1538 Hours (Continued)

(5972 Nm axle shaft torque) the actual RH wheel hub torque was approximately 108,000 Nm (30,000 Nm axle shaft torque). This approximation was based upon analysis of the engine RPM at time of failure. 30,000 Nm torque is enough to cause "one shot" failure of the axle shaft.

While this faulty electronic component was in the test rig load circuitry from the start, all previous testing remains valid because all previous loading was below 21,000 Nm at the wheel hub. Below this level, the component read accurately.

This was not a legitimate axle shaft failure. All torsion components in the RH planetary, the differential ring gear and pinion, and the differential RH output hub spline were inspected by Magna-flux procedure or red dye procedure for cracks. No cracks were detected in any other components, therefore the RH axle shaft was the only component replaced. This replaced axle shaft was Rockwell International part number 3202-5-8521.

### 7.3.2 Downtime Period at 505 Hours of the Scheduled 1538 Hours

Failure was encountered of the spiral bevel ring gear in the front axle differential assembly. Loss of power transmission occurred when a section of the ring gear broke completely out (Photographs 13 and 14). Failure mode was fatigue cracks originating at the root of the ring gear teeth (Photograph 15). Secondary damage was done to the spiral bevel pinion shaft and to the ring gear deflection block.

Agreement by telephone with David Krawchuk of the U.S. Army was to rebuild the axle and replace all parts with any primary or secondary damage. To expedite reassembly, the differential carrier assembly was shipped to Rockwell International in Oshkosh, Wisconsin, where repairs were made. Rockwell also found secondary damage to the carrier itself. The Rockwell rebuild actually replaced all components of the differential carrier assembly with the exception of the "no-spin" components. The differential carrier assembly is a self-contained assembly consisting of the no-spin differential, and spiral

## **7.0 LOW SPEED LABORATORY TEST (Continued)**

### **7.3.2 Downtime Period at 505 Hours of the Scheduled 1538 Hours (Continued)**

bevel ring gear and pinion set all completely mounted and properly adjusted. This carrier assembly (Photograph 16) then mounts into the center section of the axle assembly.

### **7.3.3 Downtime Period at 782 Hours of the Scheduled 1538 Hours**

Failure was encountered in the RH planetary of the front axle assembly. Primary failure mode appeared to be breakage through a fatigue crack in the tooth root of one of the three planet pinions (Photographs 17 and 18). Secondary damage was done to the other two planet pinions (Photographs 19 and 20), the sun pinion (Photograph 21), the planet pinion nylon bushings (Photograph 22), and the ring gear.

Although it appeared that the primary failure was through the planet pinion section (Photograph 18) which showed a definite fatigue pattern, the surface crack from which the fatigue pattern grew was of uncertain origin. This was the only failure section through any of the planet pinions which showed a fatigue pattern. The rest were typical low cycle secondary fractures.

The LH planetary of the front axle assembly was disassembled for inspection at this time. It was reassembled after no distress or cracks were found on any of the planetary components.

Agreement by telephone with David Krawchuk of the U.S. Army was to remove the LH planetary and axle shaft assembly from the rear axle assembly of the field histogram SDMHE vehicle, and install this in the RH side of the front axle assembly in the lab test unit. This assembly was like that shown in Photograph 23.

### **7.3.4 Final Failure at 865 Hours of the Schedule 1538 Hours**

Failure was encountered of the spiral bevel ring gear in the front axle differential assembly (360 hours of lab low speed testing on the part). A section of the ring gear was broken out

## **7.0 LOW SPEED LABORATORY TEST (Continued)**

### **7.3.4 Final Failure at 865 Hours of the Schedule 1538 Hours (Continued)**

(Photographs 24 and 25). Failure mode was fatigue cracks originating at the root of the ring gear teeth. Secondary damage was done to the spiral bevel pinion shaft and to the ring gear deflection rub block.

The failure was almost identical to the one which occurred after 505 hours of lab low speed testing (see 7.3.2). It was apparent that the ring gear in the Rockwell International axle assembly would not tolerate the load imposed upon it during low speed-high torque phase of laboratory testing. Per telephone call of 16 February 1989, David Krawchuk of the U.S. Army instructed that the test program per Contract DAAK70-87-C-0061 be terminated.

## 8.0 RECORD OF EVENTS DURING LABORATORY TESTING

### 26 May 1988:

Start of high speed laboratory test scheduled for 462 hours.

### 26 May 1988; 2 of 462 High Speed Test Hours:

RH side of the front axle stopped carrying load and the test stand shut down. The reason was that the no-spin differential in the front axle assembly had disconnected allowing relative motion between the RH and LH axle shafts.

The cause was in the fixture. The load dynamometers were equipped with sintered metal friction disc surface. At the 3892 Nm load level per axle shaft (4-Forward), these friction surfaces allowed a low amplitude "stick slip" condition which resulted in the gradual disconnecting of the no-spin mechanism. The solution was to replace the sintered metal friction disc surfaces with paper friction disc surfaces. This fixture problem had no effect on the driveline test components. This item involved 4 days downtime.

### 2 June 1988; 16 of 462 High Speed Test Hours:

"Wipe out" of the nylon material bushings in the LH planetary of front axle assembly, due to excessive oil temperature. See 5.3 (Page 19) for detailed discussion of this problem. There were 9 days downtime for getting new parts from Rockwell and rebuilding the planetary. There were an additional 6 days downtime to run heat rise evaluation runs to provide a proper cooling cycle.

### 17 August 1988:

End of 462 hours of high speed laboratory test. There were actually 92 additional hours of running time accumulated to obtain the 462 "load" hours required. 74 hours (5 days) were spent running at no-load during the cooling cycle added after the nylon failure of 2 June 1988. 18 hours (2 days) were spent accumulating the required spikes simulating downshifting.

## **8.0 RECORD OF EVENTS DURING LABORATORY TESTING (Cont'd)**

### **26 August 1988:**

Work completed on the laboratory test rig to start the low speed test run. This work included installing the rear axle drive shaft, and switching the two front axle load brakes (derated) to the rear, and the two rear axle load brakes (full compliment) to the front.

### **29 August 1988:**

Failed the RH axle shaft of the front axle assembly due to a faulty component in load circuitry of the RH load dynamometer. See 7.3.1 (Page 36) for detailed discussion of this problem. There were 15 days downtime for getting new parts from Rockwell and an additional 7 days downtime in rebuilding the axle assembly and reinstalling in test rig.

### **30 September 1988:**

Start of low speed laboratory test scheduled for 1538 hours.

### **9 November 1988: 505 of 1538 Scheduled Low Speed Test Hours:**

First failure of the spiral bevel ring gear in the front axle differential assembly was encountered. See 7.3.2 (Page 37) for detailed discussion of this problem. There were 17 days downtime for getting new parts from Rockwell and an additional 3 days downtime in rebuilding the axle assembly and reinstalling in the test rig.

### **6 January 1989: 782 of 1538 Scheduled Low Speed Test Hours:**

Failure was encountered in the RH planetary of the front axle assembly. See 7.3.3 (Page 38) for detailed discussion of this problem. There were 9 days downtime evaluating this failure and inspecting the LH planetary, and an additional 7 days downtime rebuilding the axle assembly and reinstalling in the fixture.



## **8.0 RECORD OF EVENTS DURING LABORATORY TESTING (Cont'd)**

### 9 February 1989: 865 of 1538 Scheduled Low Speed Test Hours:

Second failure of the spiral bevel ring gear in the front axle differential assembly was encountered. See 7.3.4 (Page 38) for detailed discussion of this problem.

### 16 February 1989:

Laboratory test was terminated per telephone call from David Krawchuk of the U.S. Army.

## 9.0 FINAL INSPECTION

Per instructions of David Krawchuk (U.S. Army), there was no final disassembly and inspection of the John Deere 6-619A engine. No final disassembly and inspection was performed because no problems were experienced with the engine during testing and because the engine was a low risk of failure component within the test program.

The Twin Disc TD61-1171 modified transmission, which accumulated 1327 total laboratory test hours was disassembled for inspection of all clutch packs, gearing, and bearings. See Appendix (A-30 through A-36) for pictorial reference of the power flow routing through the transmission, in each of its six forward and one reverse gear. The inspection revealed all components to be in very good condition. Photographs 26 and 27 are external views of the transmission. Photographs 28 through 31 are views of the disassembled clutch packs and gearing showing these to all be in very good condition.

There was a section of one gear tooth missing on the 41 tooth gear of the 3rd, 6th clutch hub and gear assembly (Photograph 32). This was judged to be due to a material defect or handling damage which probably occurred prior to shipment of the transmission from the manufacturer. No evidence was found of the missing gear tooth piece in the transmission sump or oil flow circuit. The only gear in mesh with this damaged 41 tooth gear is also a 41 tooth gear (on the 2nd, 5th clutch hub) (see Appendix A-32). This mating gear displayed on the two mating teeth, an etched outline of the damaged gear tooth, indicating this damage had been there for quite some time.

It could not be said that the manufacturer (Twin Disc) was lacking in quality control because of uncertainty as to how and when this tooth damage occurred. It could have been a material defect allowing the gear tooth piece to pop out during the manufacturer's functional testing following the original build. This is a very rarely seen defect in transmission gearing. Because of the excellent condition of the remaining teeth on the subject gear, as well as all other gears in the transmission, this is not considered to be a problem with which to be concerned.

## 9.0 FINAL INSPECTION (Continued)

Following inspection the transmission was completely reassembled. The only part replacements made were a new 3rd, 6th clutch hub and gear assembly and new gaskets on the oil collectors and the main transmission housing.

The Rockwell International front axle assembly was disassembled for inspection. Photographs 24 and 25 show the failed spiral bevel ring gear which was previously discussed in 7.3.4 (Page 38). The LH outer planetary assembly components showed no abnormal wear or distress. These parts accumulated 1313 total laboratory test hours. They were installed following the nylon bushing material failure associated with excessive oil temperature (see 5.3 on Page 19). The RH planetary assembly was not disassembled for inspection. This assembly was from the SDMHE field vehicle (see 7.3.3 on Page 38) and had accumulated only 83 lab test hours. It was reinstalled in the LH side of rear axle assembly of the SDMHE field vehicle.

Following inspection, the front axle assembly was loosely reassembled. There was no spiral bevel ring gear, no planetary or sun gears in the RH planetary and no sealant on the housing flanges.

The Rockwell International rear axle assembly was disassembled for inspection. Photograph 33 is an external view of the complete axle assembly with the load dynamometer attachment adapters still in place on the outer hubs. This assembly had accumulated 865 total hours of laboratory testing (low speed program). No abnormal wear or distress was found on any of the components.

Following inspection, the rear axle assembly was completely reassembled with no parts replaced.

## 10.0 CORROSION/DETERIORATION PREVENTION AND CONTROL

All external surfaces of the selected driveline components (engine, transmission, torque converter, and axles) were protected from rust corrosion by paint, which was applied by the respective manufacturers prior to shipment from their factories. All openings in these component assemblies were sealed by non-metallic seals or gaskets, with the exception of the standard vents. Internal parts of these component assemblies were originally rust protected by the oil coating they get during test stand runs made as they leave their production assembly lines. The oils used during testing, MIL-L-2104D and GL-5, were non-corrosive to the internal materials. The engine cooling system was protected by use of a corrosion inhibitor. All electrical connectors on the engine and transmission were tin plated for corrosion resistance and sealed by rubber type seals.

The external surfaces of the drive shafts were unpainted as originally received. They were covered with a light film of oil and wrapped in waxed paper. Before exposure to humidity above 35% or prolonged storage, these parts were cleaned and painted. The splined shafts were protected with grease.

All laboratory test rig metal components were also painted for rust protection.

If any of these driveline components were to be returned to the U.S. Army or stored in an unassembled condition, each piece would be protected by covering with a rust resistant film compound and properly wrapped in paper.

## 11.0 CONCLUSIONS

The John Deere 6-619A engine, Twin Disc TD61-1171 modified transmission, Twin Disc 8FLW-1611-1 torque converter, and Borg Warner drive shafts all demonstrated acceptable performance over the duration of the laboratory testing. The engine, transmission, torque converter, transmission input drive shaft, and front axle input drive shaft have accumulated 1327 total laboratory test hours (462 high speed hours and 865 low speed hours) which, with the applicable acceleration factors, equates to 4347 total field vehicle hours (1197 high speed transport hours and 3150 low speed materials handling hours). The rear axle input drive shaft accumulated 865 total laboratory test hours (all low speed) which equates to 3150 total field vehicle hours (all low speed materials handling).

Based upon the absence of any indicated performance degradation over the 1327 hours of laboratory testing, and the lack of any abnormal wear or other distress observed during final teardown inspection, it was judged that all of the aforementioned driveline components could have successfully completed 2000 hours of laboratory testing, and would be acceptable for the SDMHE application.

The Rockwell International PRC676 (12.76 ratio) axle assembly was judged to be deficient for the SDMHE application, based upon the results of the laboratory test program. The deficiencies were particularly demonstrated in the front axle application. In the proposed SDMHE application, the front axle assembly has a much more severe duty cycle than does the rear axle application.

The first deficiency found with the PRC676 (12.76 ratio) axle assembly was inadequate cooling characteristics during high speed operation. The use of a nylon material bushing/bearing in the outer planetaries limited the allowable maximum oil temperature to approximately 235°F. During sustained high speed transport in the SDMHE vehicle, maintenance of 235°F maximum oil temperature cannot be assured. An external oil cooler could be added to the center (differential) area of the axle assembly, but this affords little relief to the outer planetary area due to very minimal oil flow between the two areas.

The second deficiency found with the PRC676 (12.76 ratio) axle assembly was inadequate strength of the spiral bevel ring gear in the differential. Two almost identical, fatigue

## 11.0 CONCLUSIONS (Continued)

failures of this ring gear occurred during the low speed (high torque) portion of the laboratory testing.

The question has been asked as to why were so many low speed failures experienced on this axle assembly while at the same time the Army has 10K Rough Terrain Forklifts that operate on the beach and in rough terrain without this kind of axle failure. Basically, the Army's past and present 10K Rough Terrain Forklifts are forklift adaptations of commercial 10K Wheel Loaders. The axles in these machines are designed for the high wheel torque applications of wheel loaders, such as trench digging and loading the bucket of materials ranging from sand to rock. These axles should easily withstand loads imposed by the forklift adaptations. However, these axles were not designed for 45 MPH operation.

Since 45 MPH operation was a primary requirement for the SDMHE application, this severely limited the opportunity for finding test component axles which had been designed specifically for wheel loader applications. Based upon the expected axle torque during the estimated SDMHE duty cycle, the design evaluation work with Rockwell International concluded that the axle assembly selected would be acceptable. As it turned out, the expected axle torques used during design evaluation and component selection were lower than the actual axle torques measured later during the SDMHE field histogram (specifically when the vehicle became mired down in beach sand operations). The laboratory test results showed that with the actual measured torques taken into account, the durability strength of the differential ring gear in the selected axle assembly was not adequate.

Rockwell informed Deere at the conclusion of the parts selection process that the torque transmitting components (shafts, gears, bearings) of these particular axles were considered to be acceptable for the intended SDMHE application, but that the axle housings would require beefing up of some overstressed areas for any long term field vehicle use. This information was documented by Deere in Progress Report (A001) for December 1987 for Contract DAAK70-87-C-0061. Because of this overstress condition, Rockwell refused to certify their axle assembly for vehicle use, beyond the time required for Deere to conduct the field histogram.

## 12.0 RECOMMENDATIONS

Based upon this testing program, future efforts on this activity should be concentrated upon axle components for the SDMHE application. Axle compartment oil cooling, during high speed transport, must be adequately addressed in combination with the temperature sensitivity of axle components.

Use of the axle load data contained in this report, which was obtained during the field histogram, is recommended for potential axle suppliers. Knowledge of this loading will assist the supplier in providing an axle assembly of adequate strength for the materials handling applications of SDMHE.

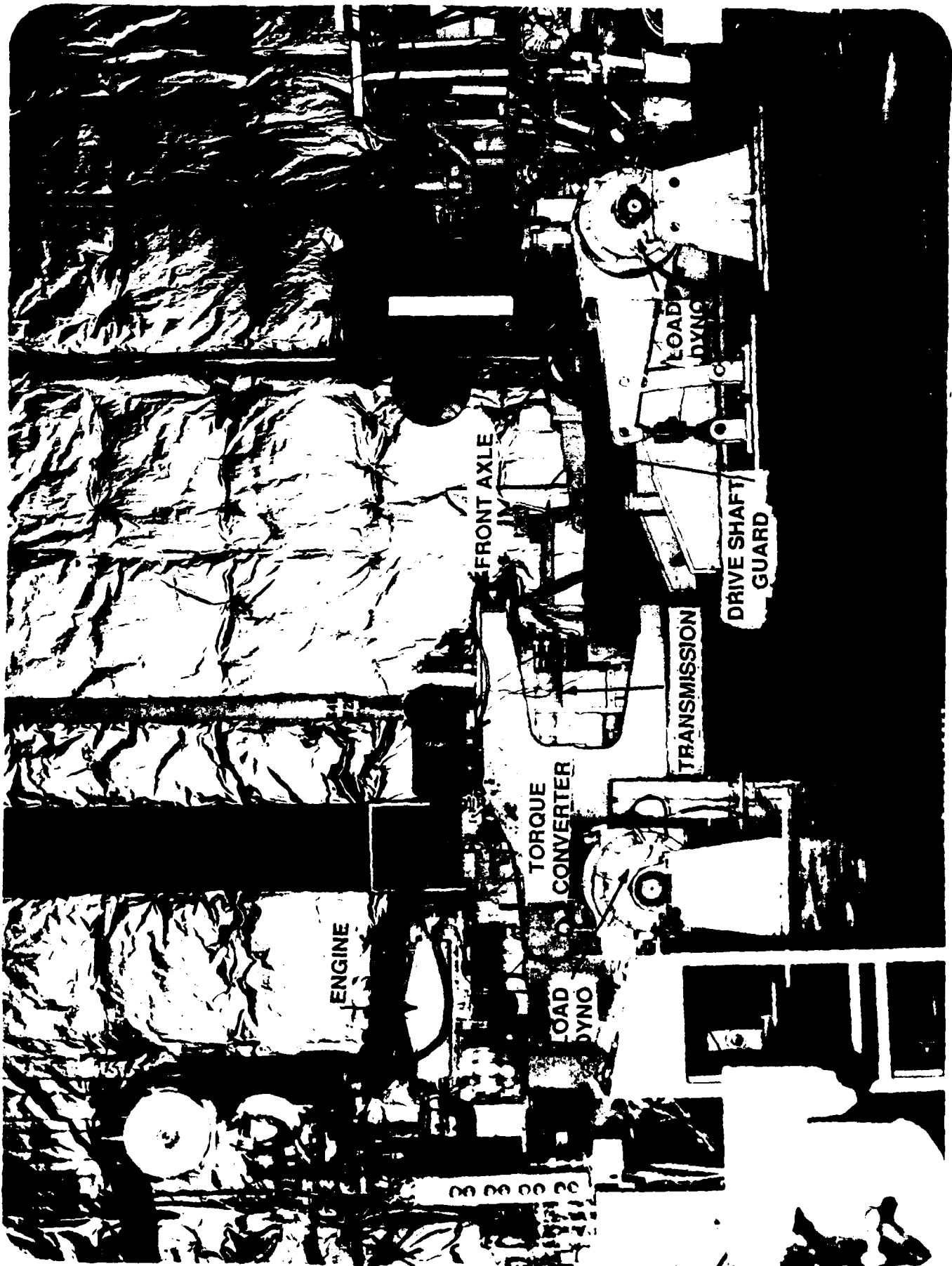
### 13.0 PHOTOGRAPH SUPPLEMENT

- Photograph 1 Actual Laboratory Test Rig (RH Side View)
- Photograph 2 Laboratory Test Control Room
- Photograph 3 Heat Distress of Planet Pinion Shafts of LH Planetary - Front Axle
- Photograph 4 Replaced Planet Pinion Shafts of RH Planetary - Front Axle
- Photograph 5 New Planet Pinion Shafts for RH Planetary - Front Axle
- Photograph 6 Distressed Planet Pinion from LH Planetary - Front Axle
- Photograph 7 Distressed Sun Pinion from LH Planetary - Front Axle
- Photograph 8 Replaced Bearings from LH Planetary - Front Axle
- Photograph 9 Replaced Bearings from LH Planetary - Front Axle
- Photograph 10 Replaced Planet Pinion Thrust Washers of LH Planetary - Front Axle
- Photograph 11 SDMHE
- Photograph 12 Failed RH Axle Shaft of Front Axle Assembly
- Photograph 13 First Ring Gear Failure of Front Axle Assembly
- Photograph 14 First Ring Gear Failure of Front Axle Assembly
- Photograph 15 Fatigue Cracks on First Ring Gear Failure
- Photograph 16 Differential Carrier Assembly
- Photograph 17 Suspected Primary Failure Planetary Pinion
- Photograph 18 Suspected Primary Failure Section of Pinion
- Photograph 19 Second Planetary Pinion w/Secondary Damage
- Photograph 20 Third Planetary Pinion w/Secondary Damage
- Photograph 21 Sun Pinion w/Secondary Damage
- Photograph 22 Failed RH Planetary of Front Axle
- Photograph 23 Planetary and Axle Shaft Assembly Removed from Axle Assembly
- Photograph 24 Final Spiral Ring Gear Failure
- Photograph 25 Final Spiral Ring Gear Failure
- Photograph 26 Transmission External View
- Photograph 27 Transmission External View
- Photograph 28 7-Inch Clutch Pack (2nd, 5th and 1st, 4th)
- Photograph 29 7-Inch Clutch Pack (3rd, 6th, and Rev)
- Photograph 30 9-Inch Clutch Pack (Rev, 1st, 2nd, 3rd, and 4th, 5th, 6th)
- Photograph 31 Compound Shaft
- Photograph 32 3rd, 6th clutch Hub Gear Tooth Defect
- Photograph 33 Complete Rear Axle Assembly



PHOTOGRAPH 1

8902090-18



Actual Laboratory Test Rig

PHOTOGRAPH 2

8903106-13

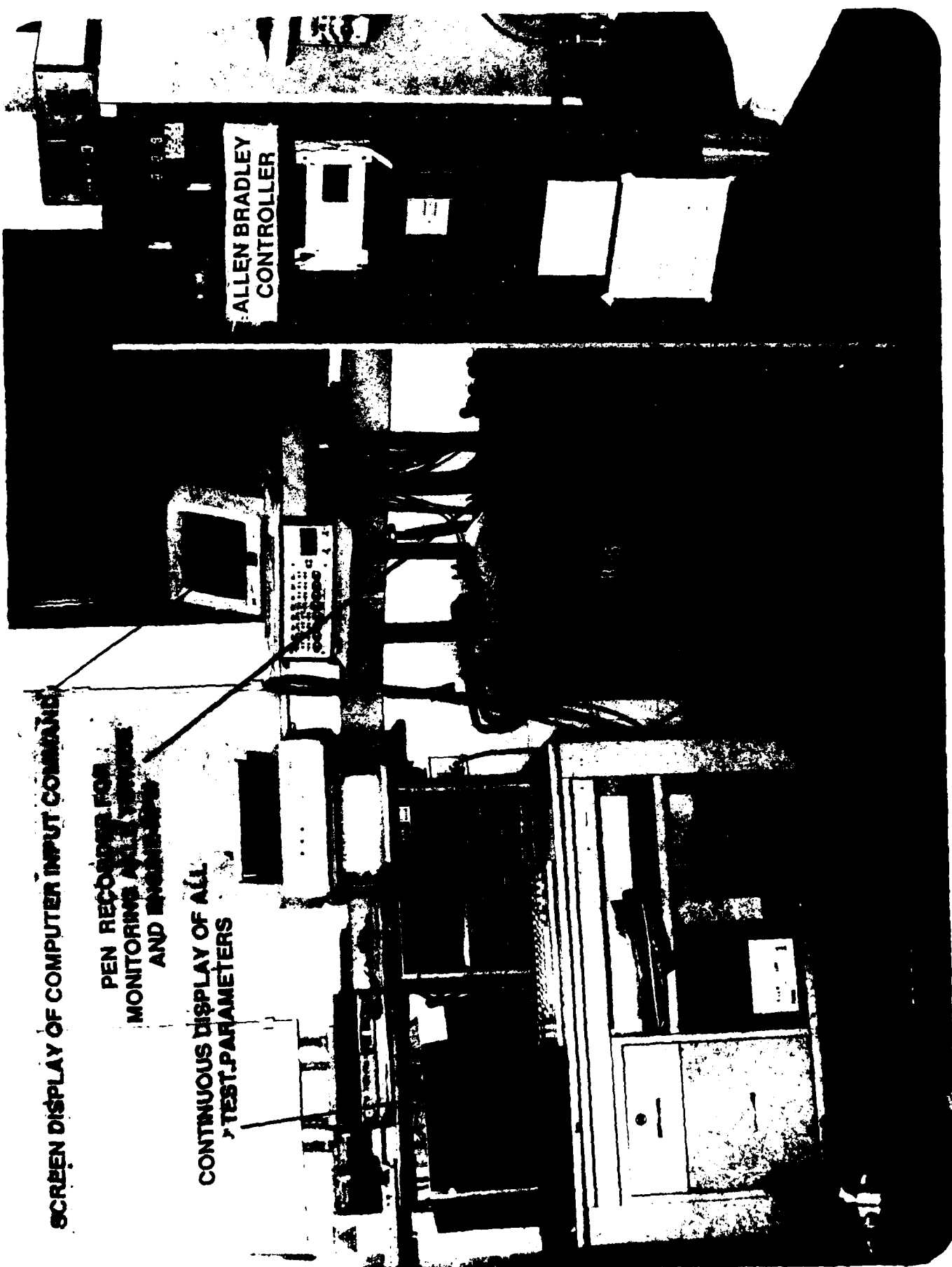
SCREEN DISPLAY OF COMPUTER INPUT COMMANDS

PEN RECORDER FOR  
MONITORING ALL TEST  
AND ENGINE DATA

CONTINUOUS DISPLAY OF ALL  
TEST PARAMETERS

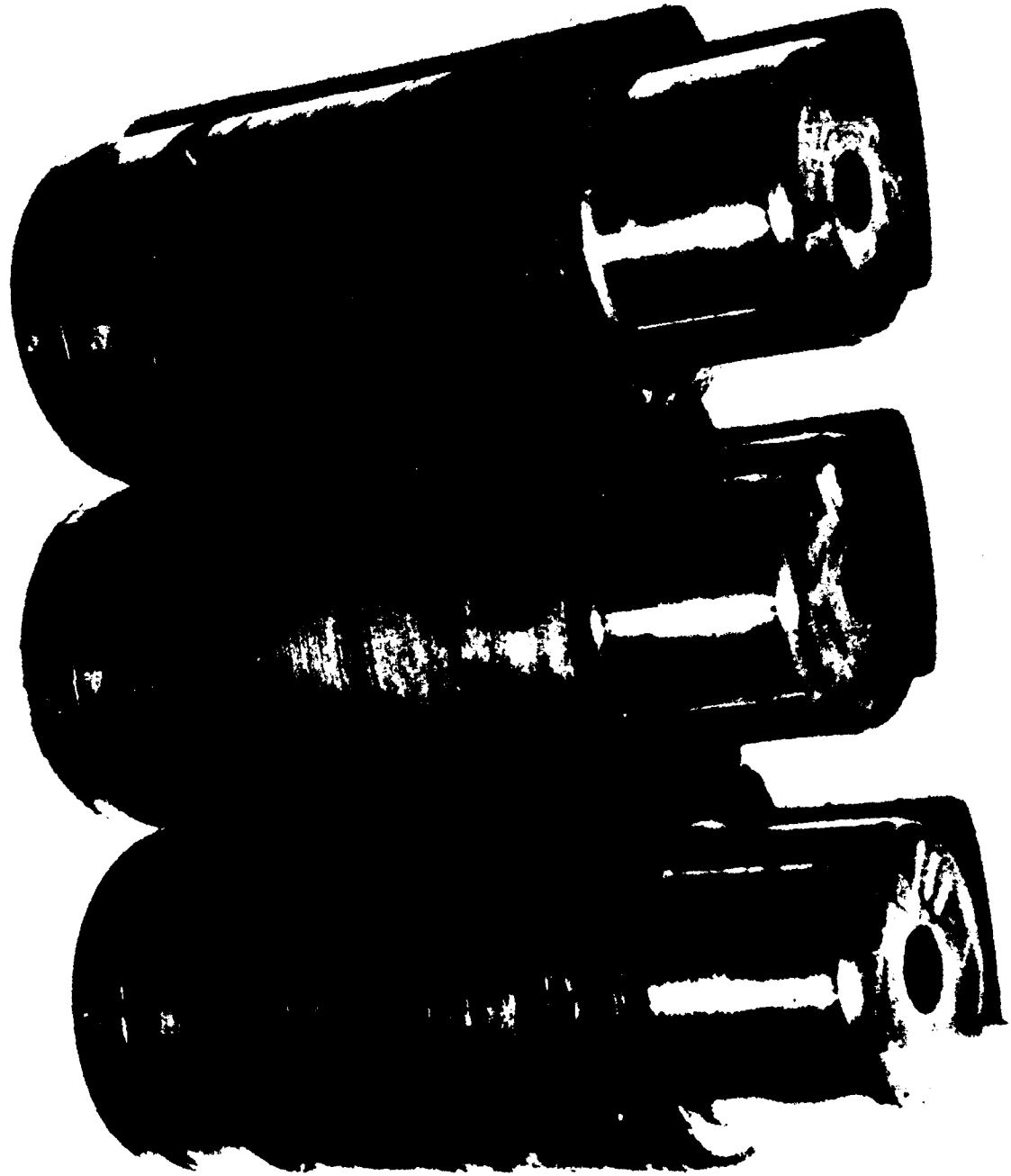
ALLEN BRADLEY  
CONTROLLER

Laboratory Test Control Room



PHOTOGRAPH 3

880608 J-9



Heat Distress of Planet Pinion Shafts of LH Planetary - Front Axle

PHOTOGRAPH 4

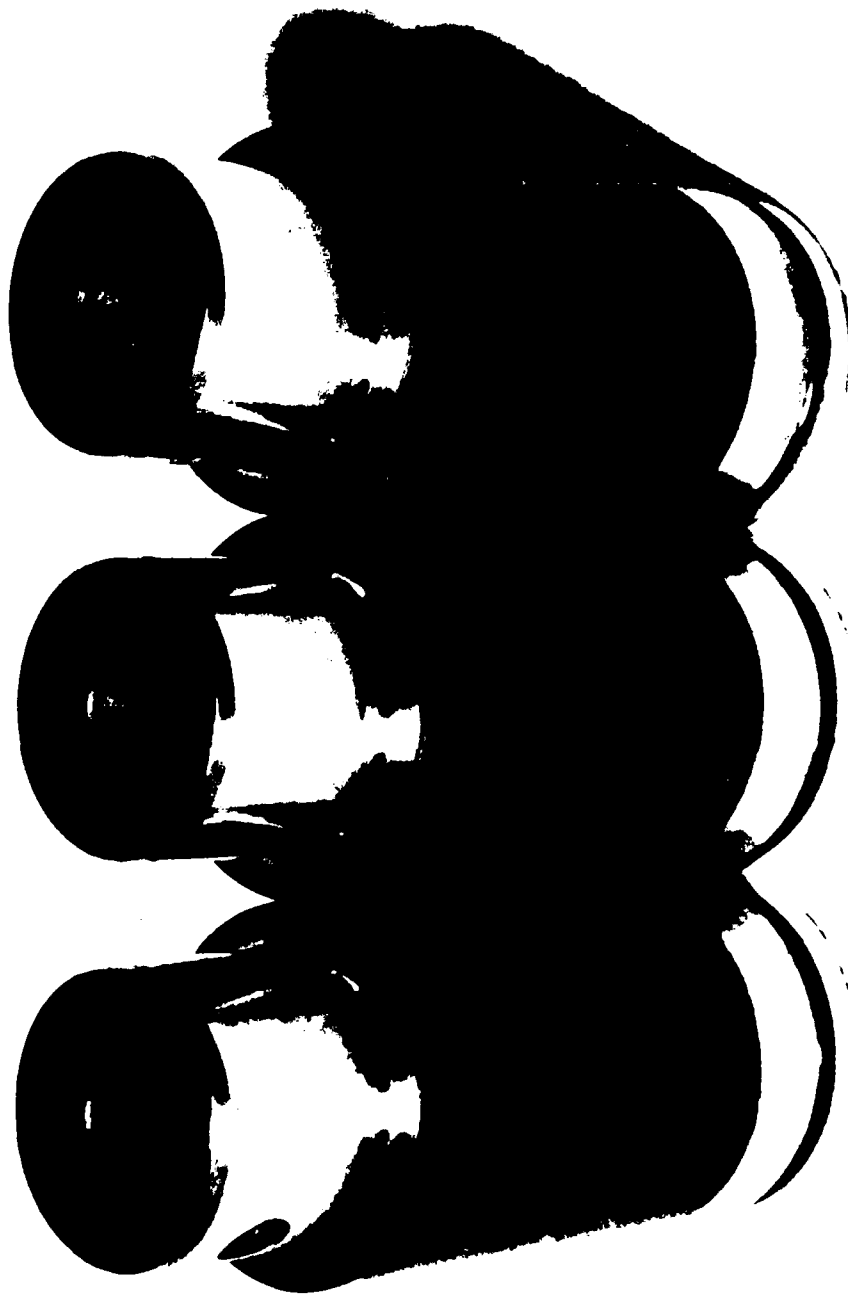
810004-9



Replaced Planet Pinion Shafts of RH Planetary - Front Axle

PHOTOGRAPH 5

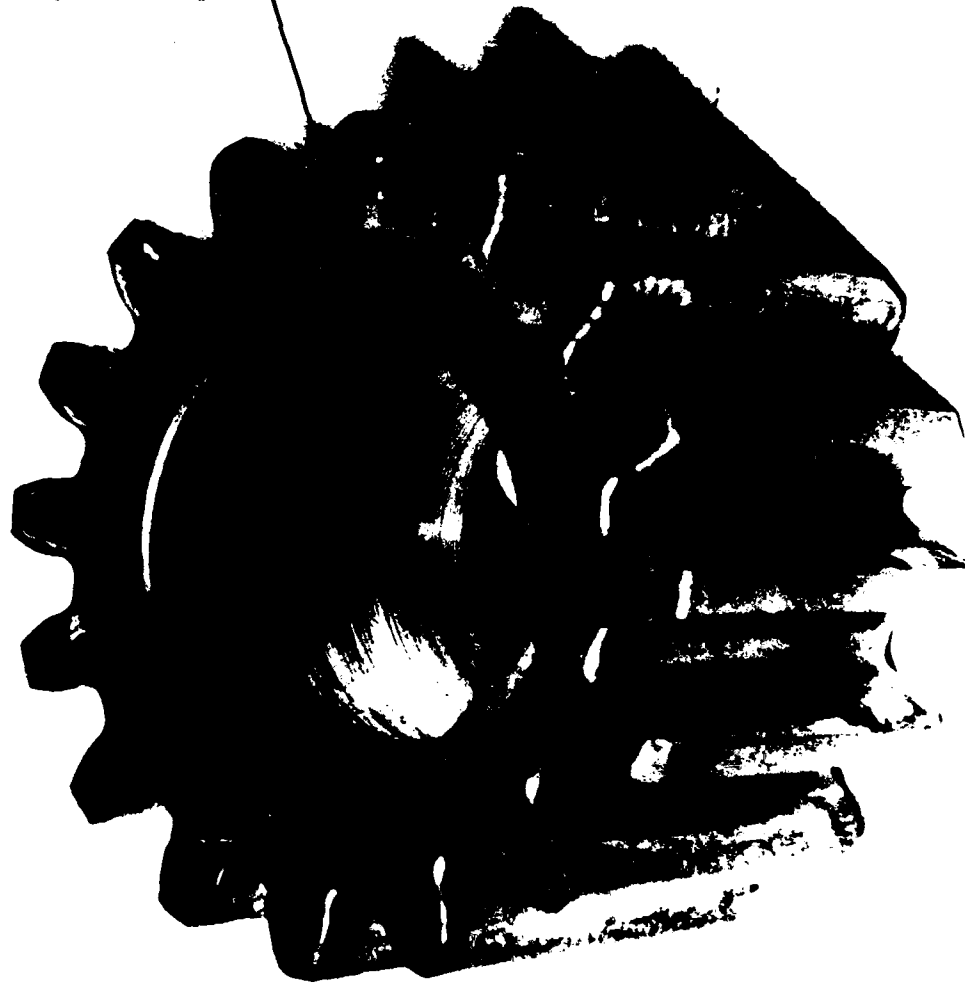
21-4802988



New Planet Pinion Shafts for RH Planetary - Front Axle

PHOTOGRAPH 6

HEAT DISTRESS  
(METAL DISPLACEMENT)



Distressed Planet Pinion from LH Planetary - Front Axle

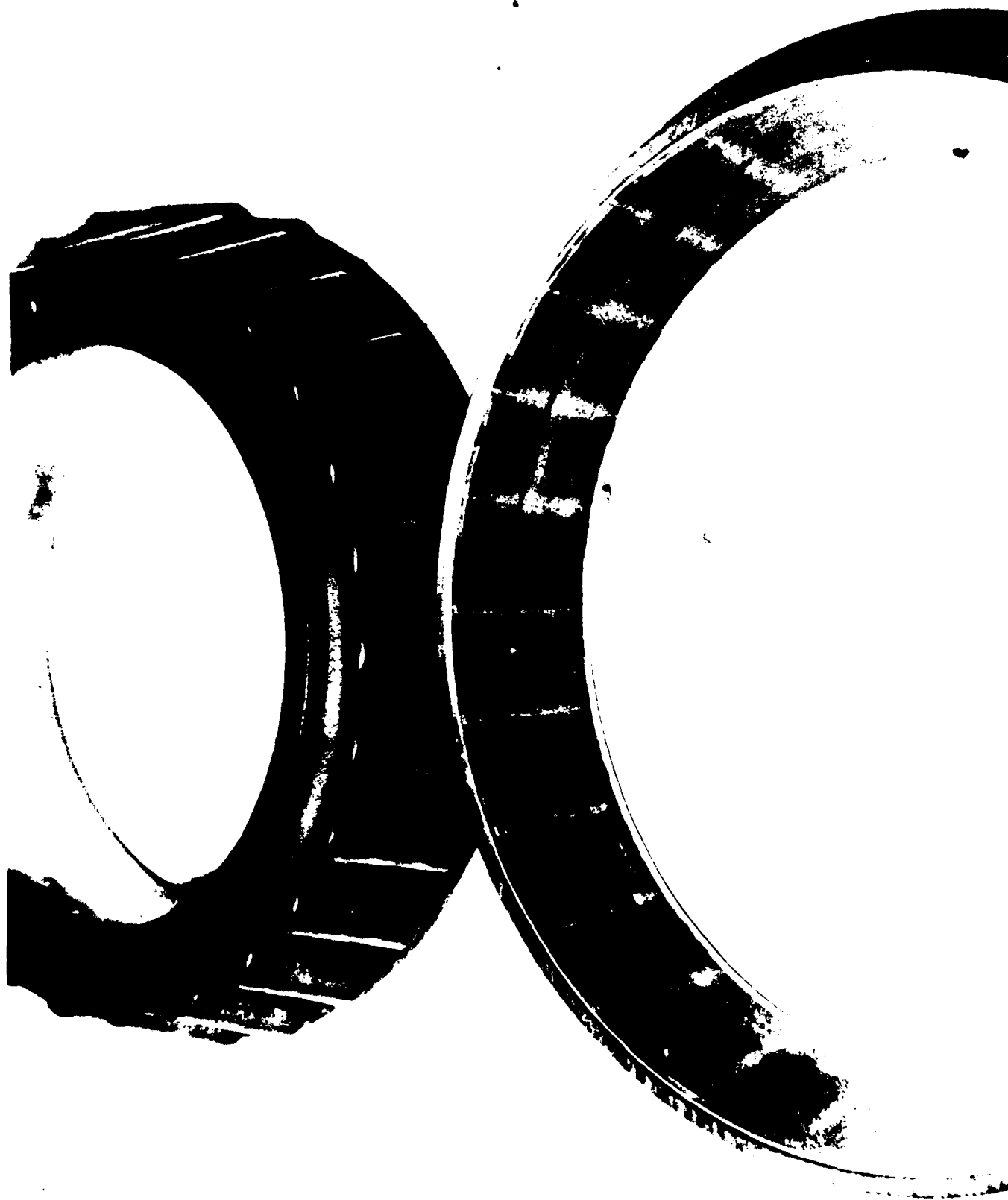
PHOTOGRAPH 7



HEAT DISCOLORATION AND  
METAL DISPLACEMENT

Distressed Sun Pinion from LH Planetary - Front Axle

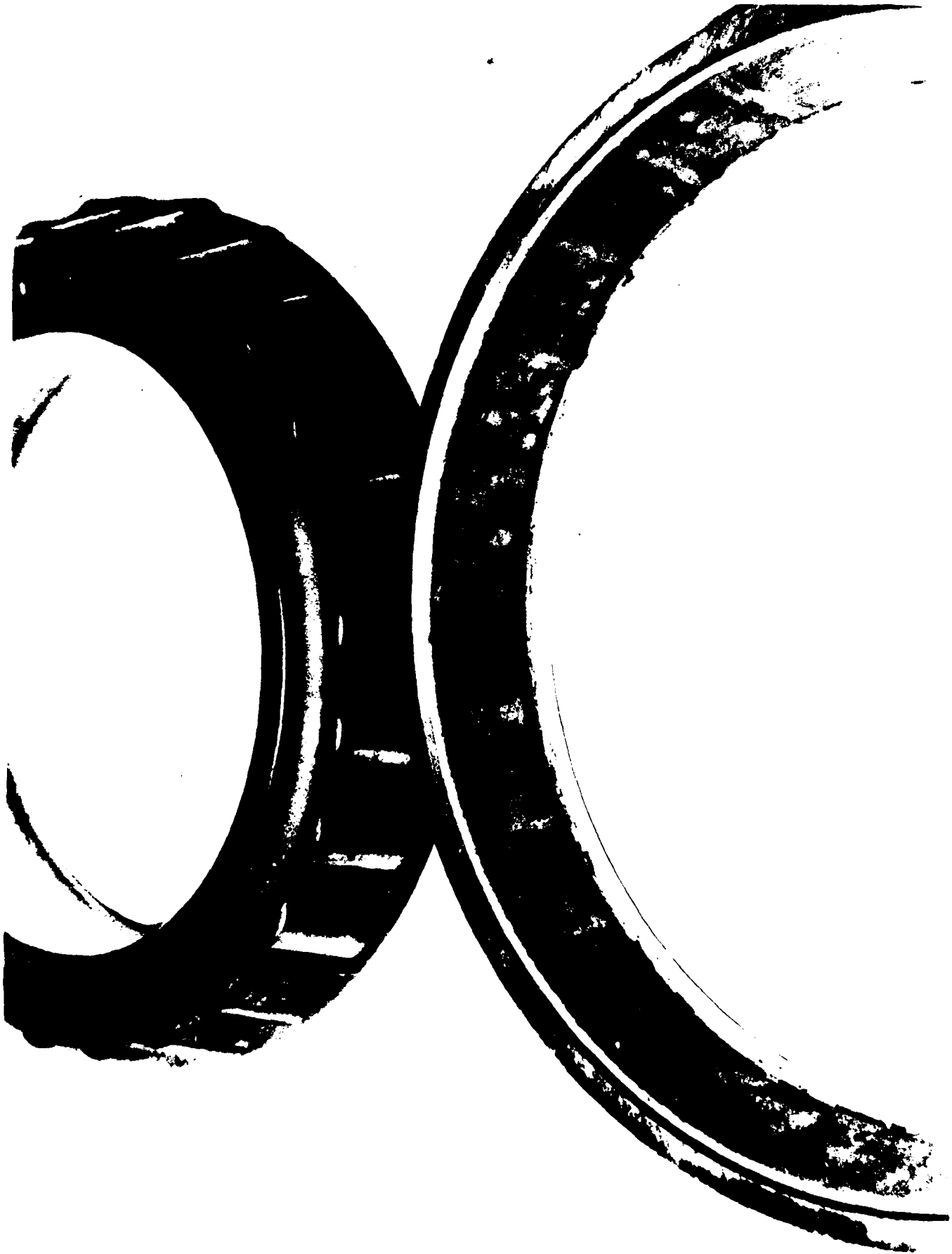
54 H800 008



Replaced Bearings from LH Planetary - Front Axle

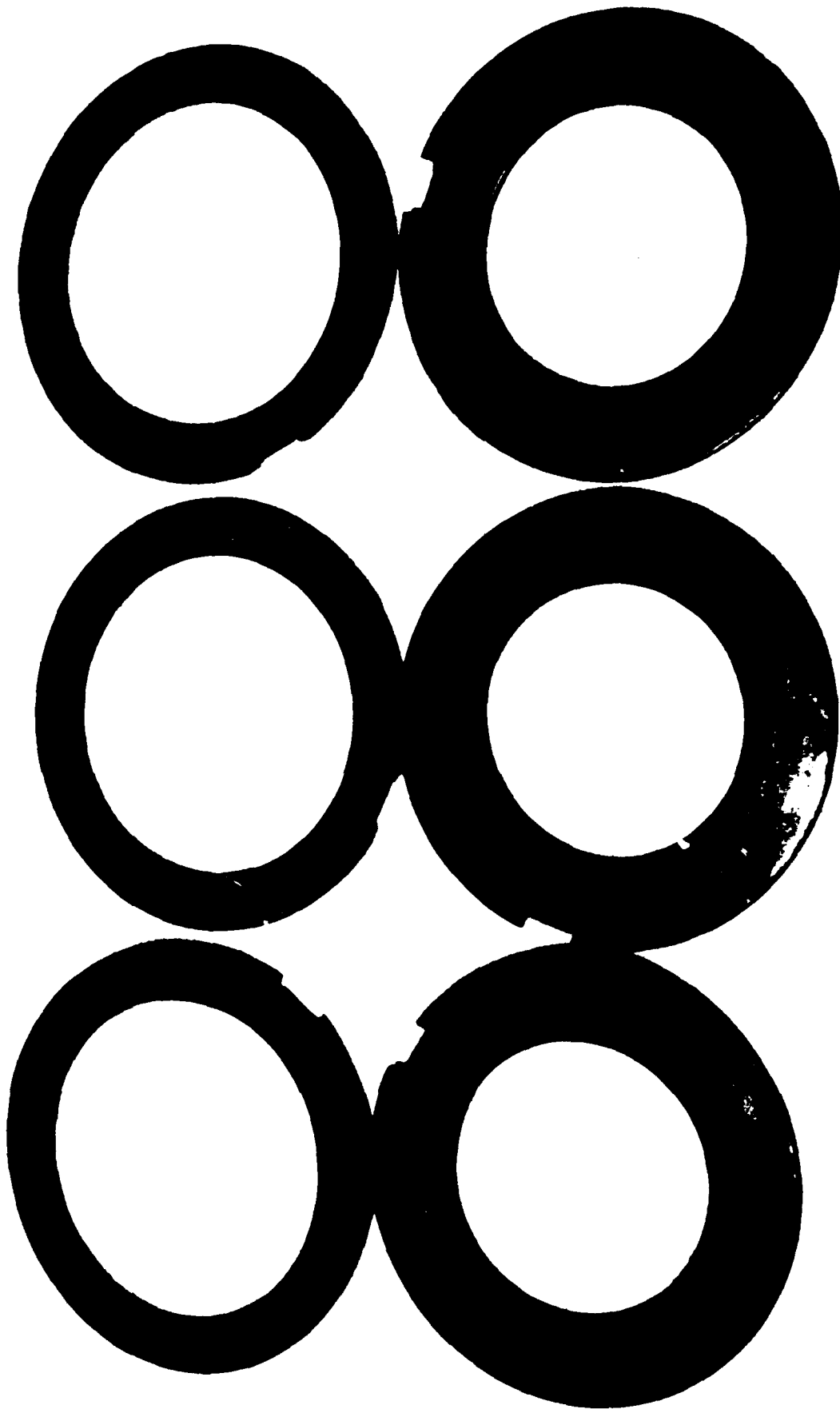


81-4809088



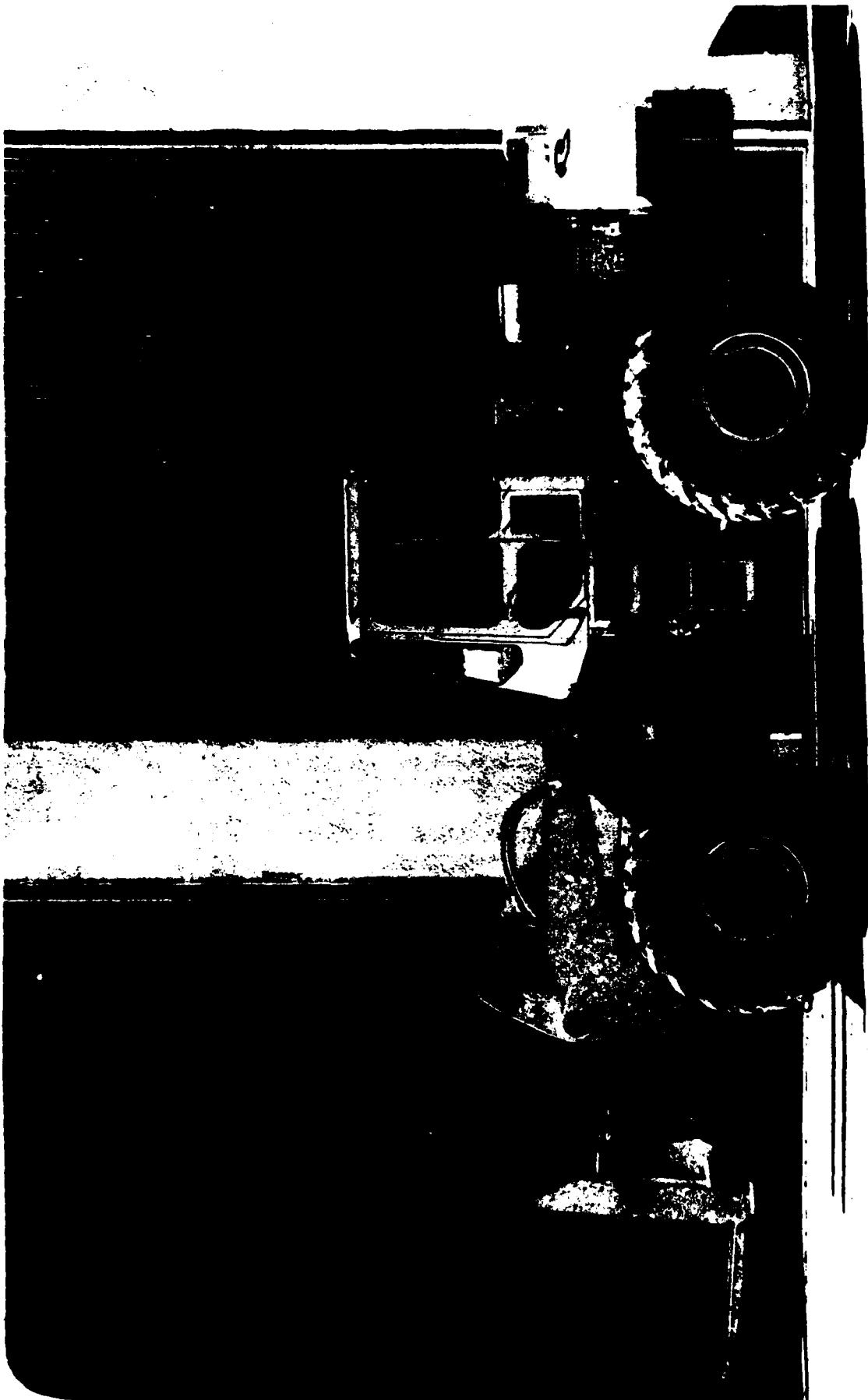
Replaced Bearings from LH Planetary - Front Axle

C-H 809088



Replaced Planet Pinion Thrust Washers of LH Planetary - Front Axle

090327A 5



SDMHE FIELD VEHICLE



Failed RH Axle Shaft of Front Axle Assembly

21-3139082



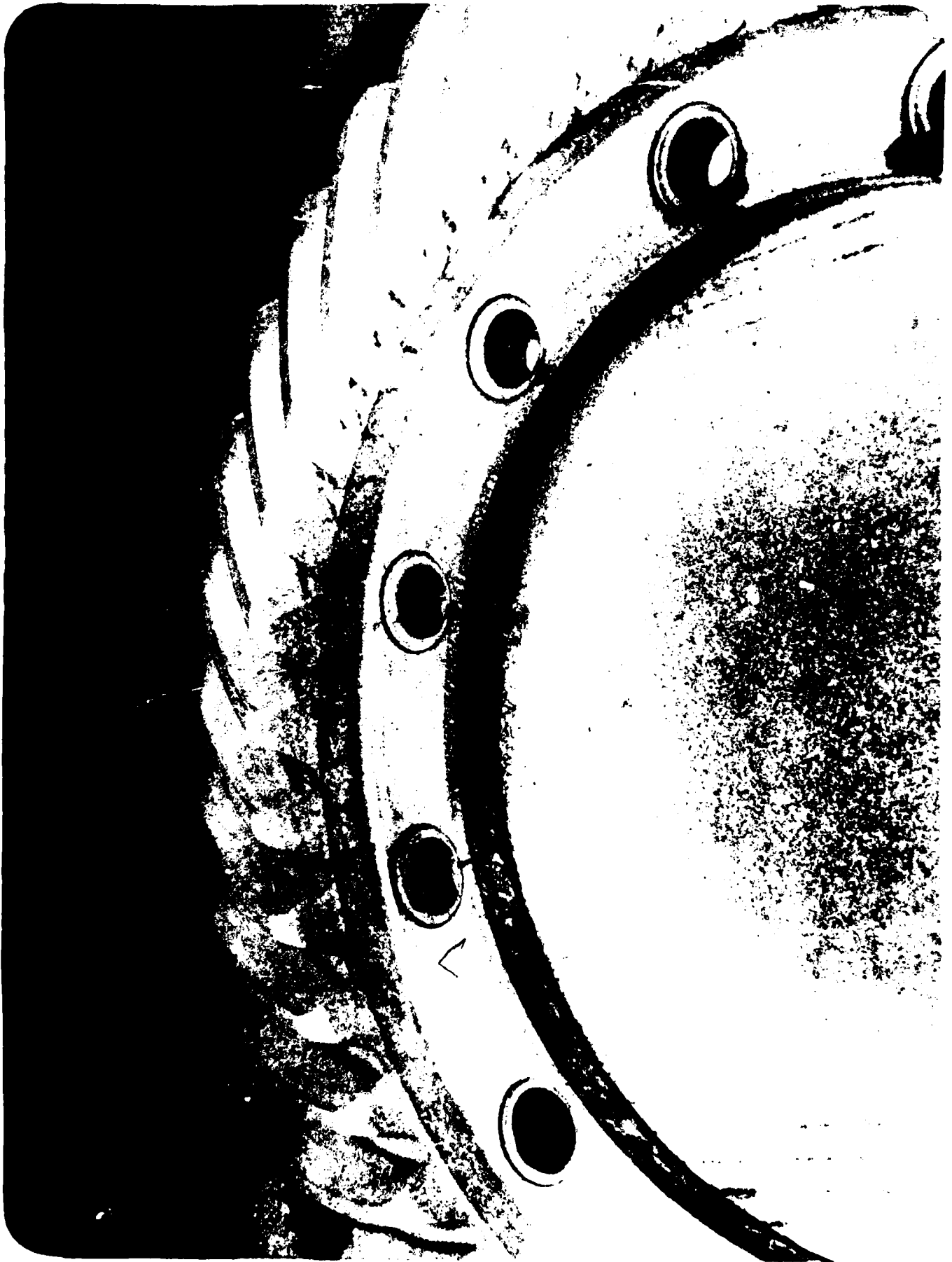
First Ring Gear Failure of Front Axle Assembly

08-11-70-77



First Ring Gear Failure of Front Axle Assembly

890702 C-6



Fatigue Cracks on First Ring Gear Failure



Differential Carrier Assembly

290327A-12



6-3/5/048



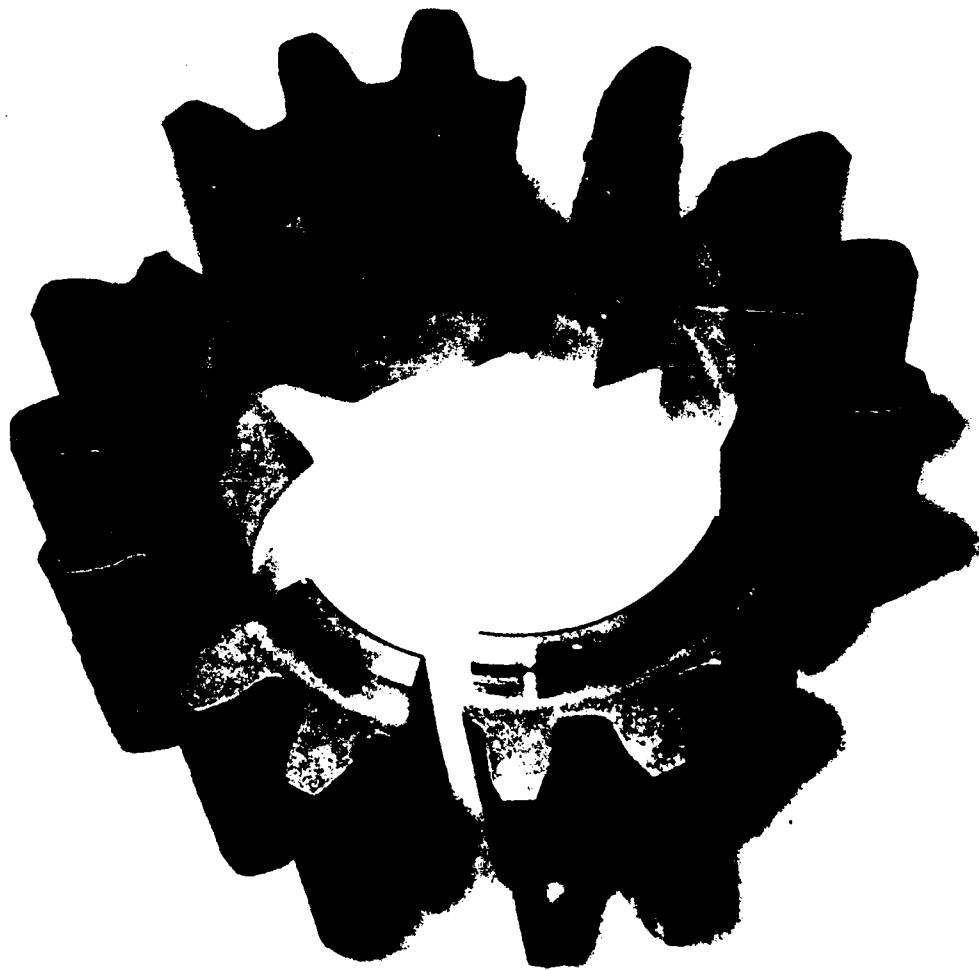
**Suspected Primary Failure Planetary Pinion**

21-3/15/88



Suspected Primary Failure Section of Pinion

8721312-4

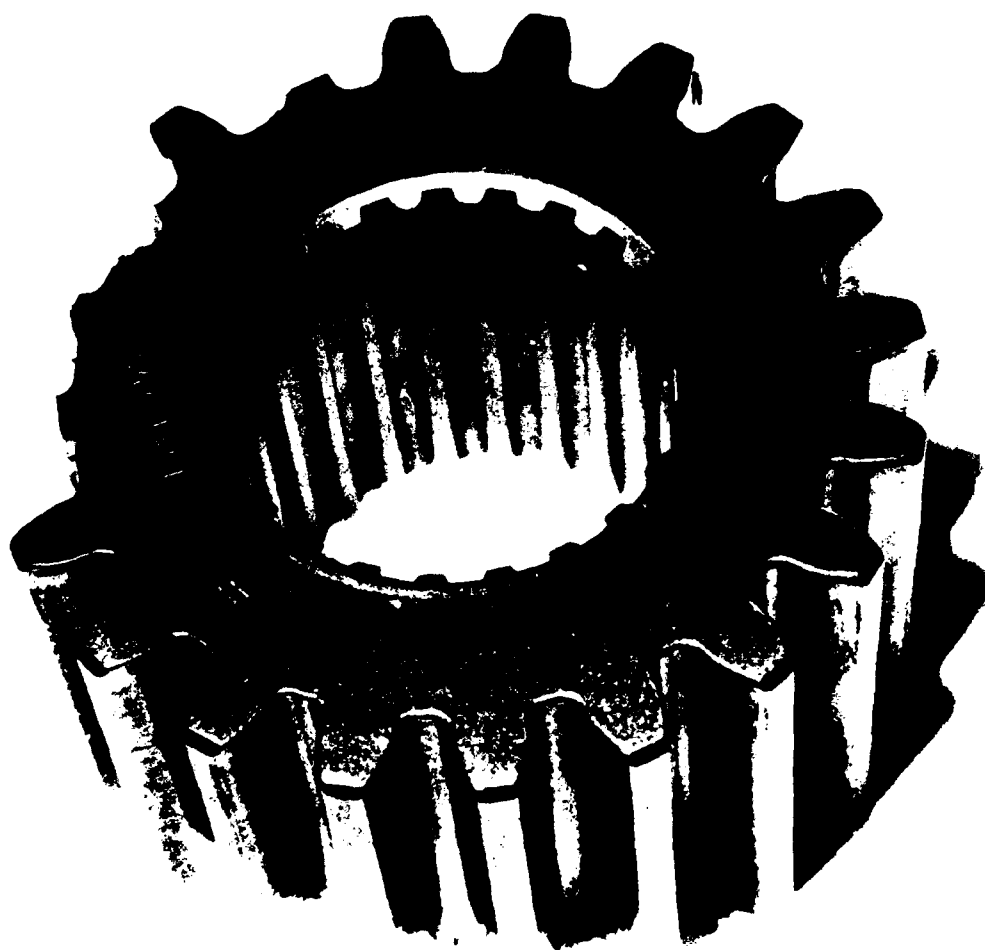


**Second Planetary Pinion w/Secondary Damage**

890151E-15



Thlrd Planetary Plnion w/Secondary Damage



Sun Pinion w/Secondary Damagae

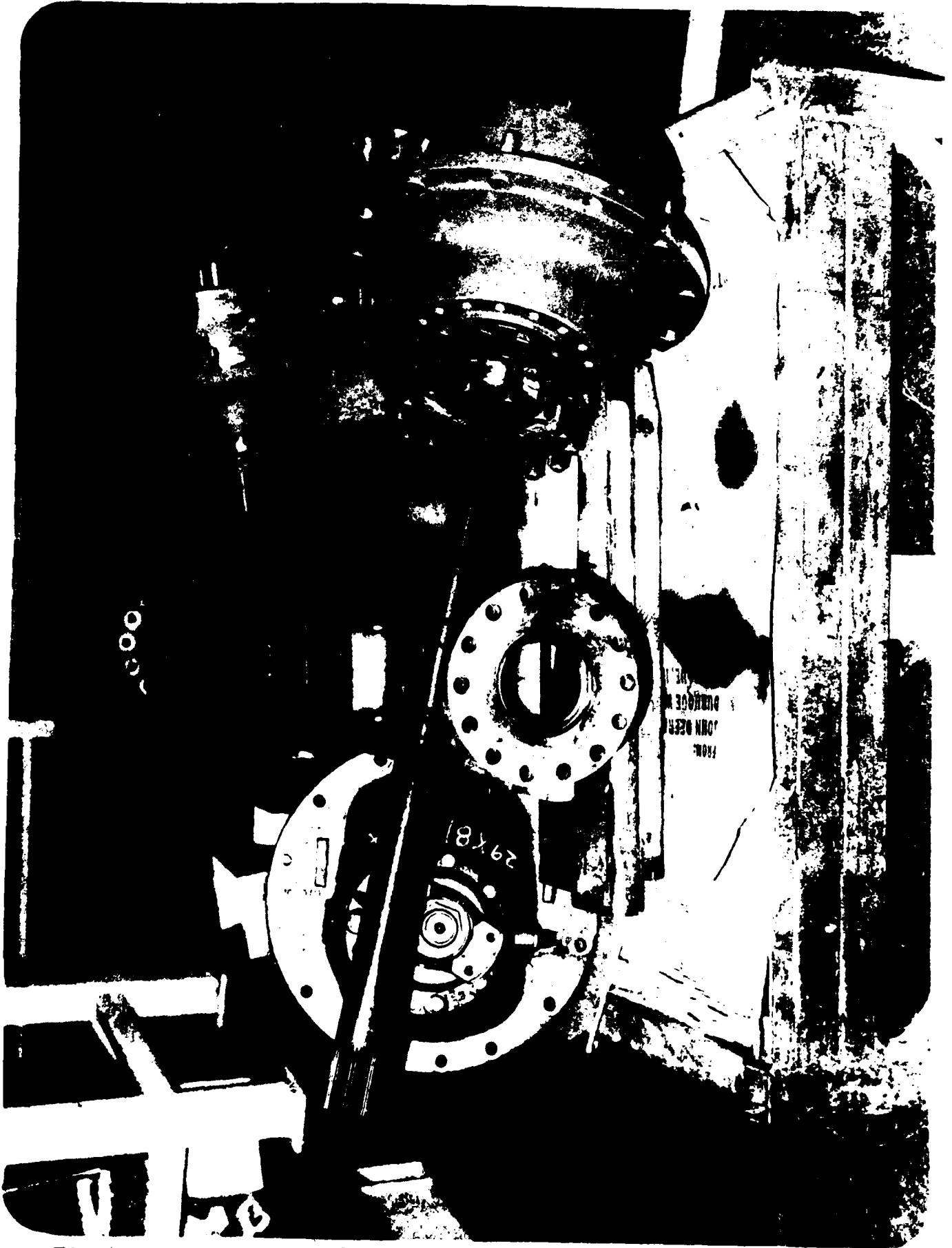
8701312-13



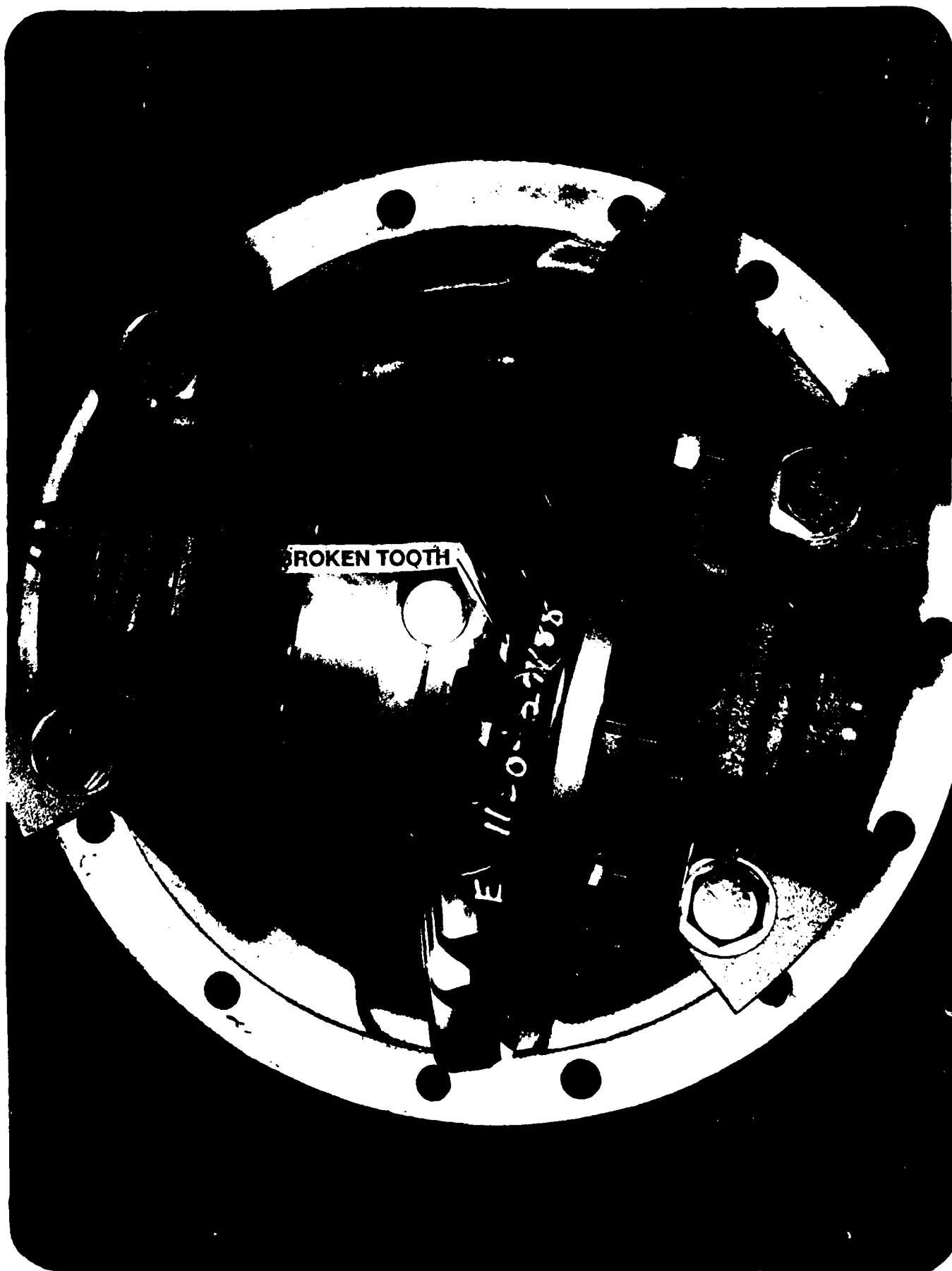
Failed RH Planetary of Front Axle

*Bordwell*

890327A-75



Planetary and Axle Shaft Assembly removed from Axle Assembly

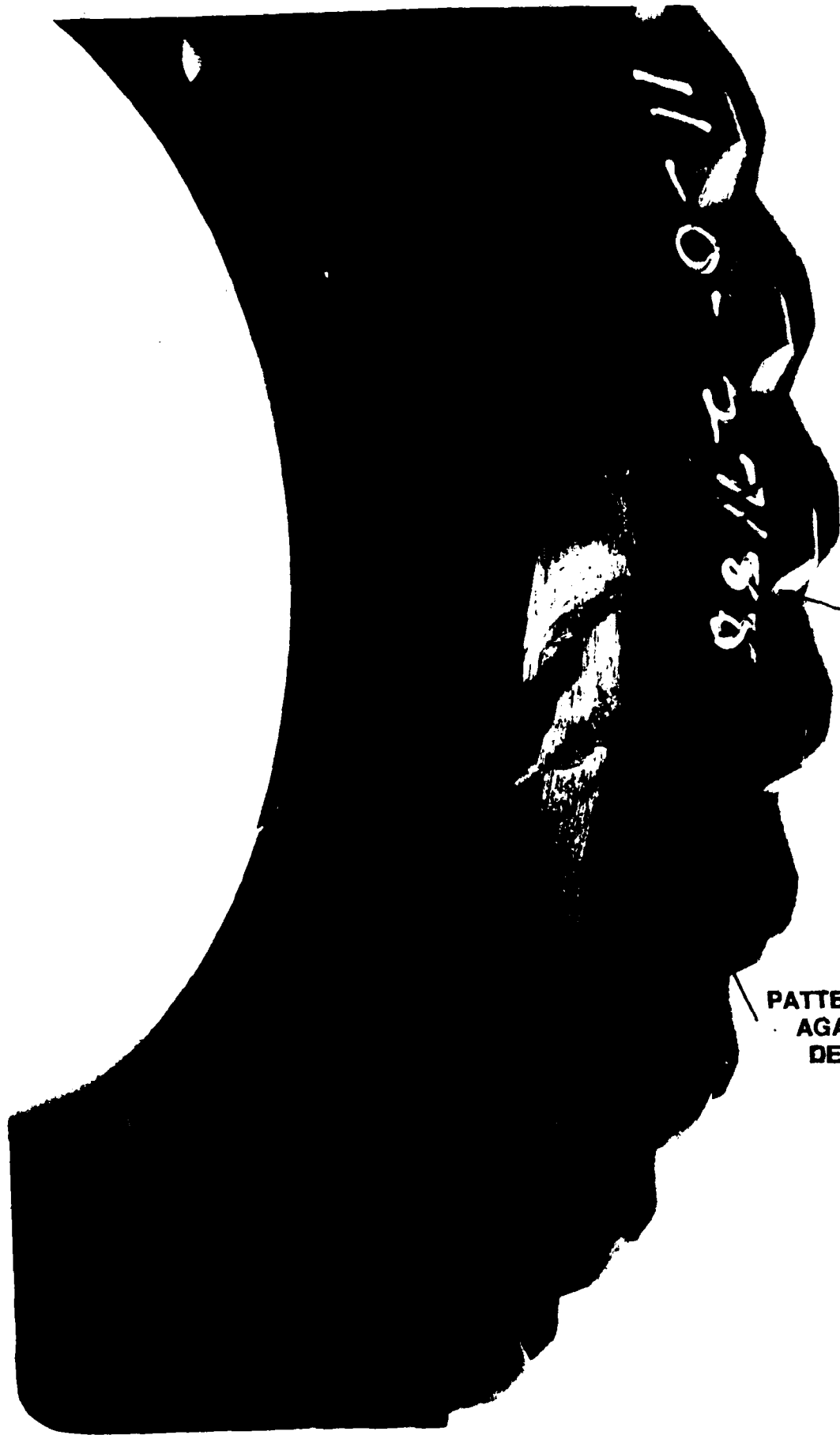


Final Spiral Ring Gear Failure



PHOTOGRAPH 25

840220A-12

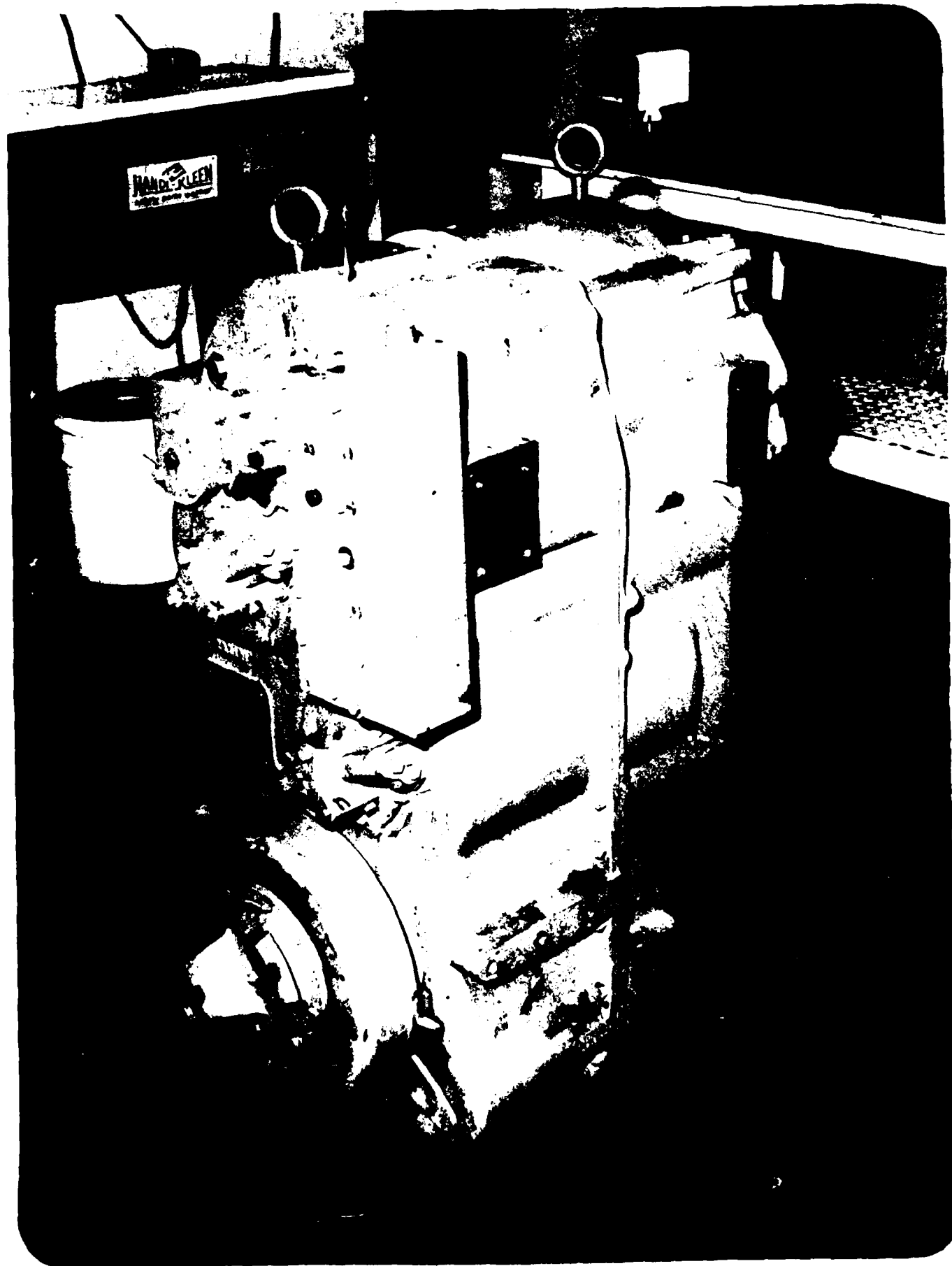


BROKEN TOOTH

PATTERN FROM RUBBING  
AGAINST RING GEAR  
DEFLECTION STOP

Final Spiral Ring Gear Failure

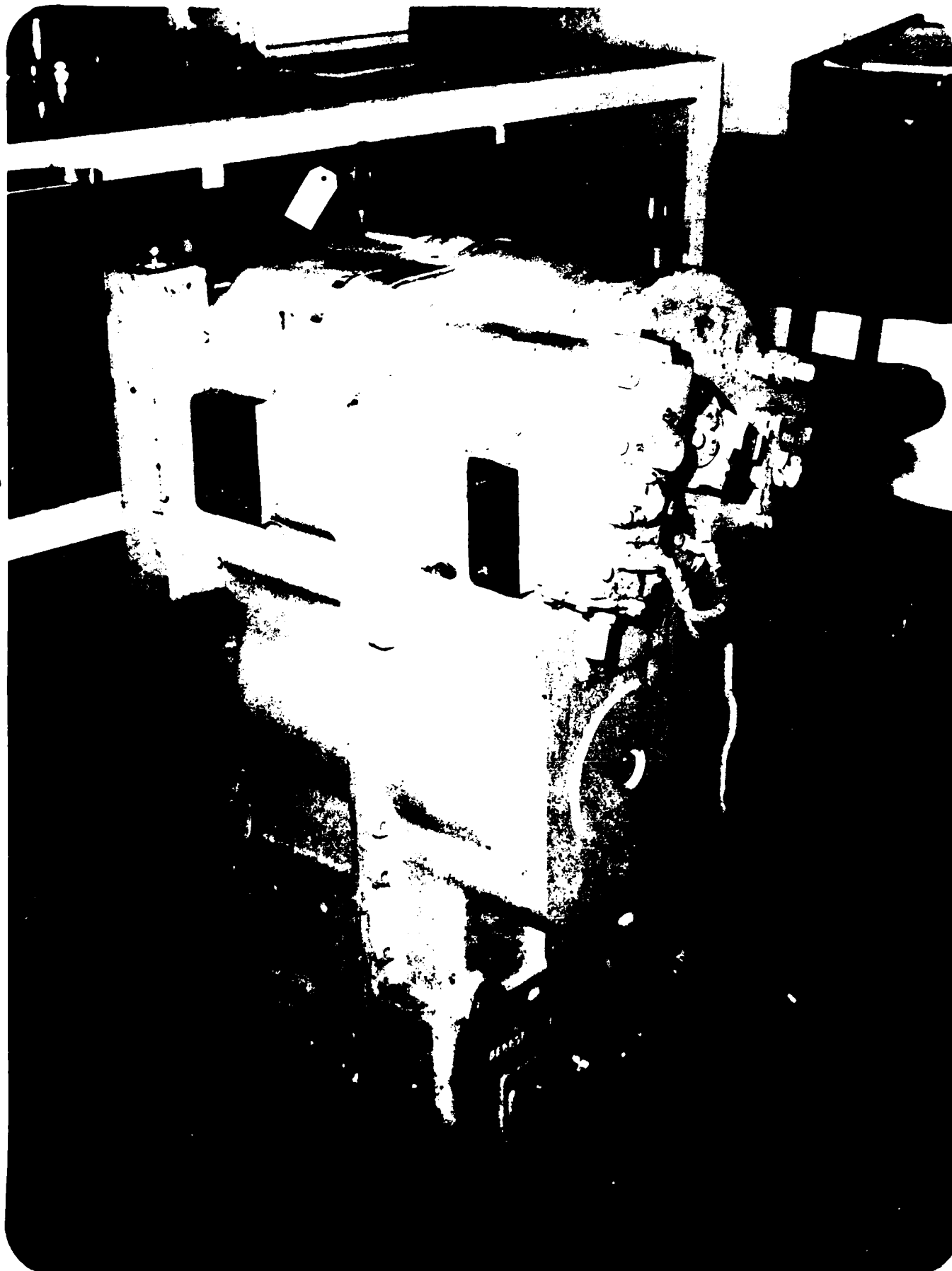
26-3105048



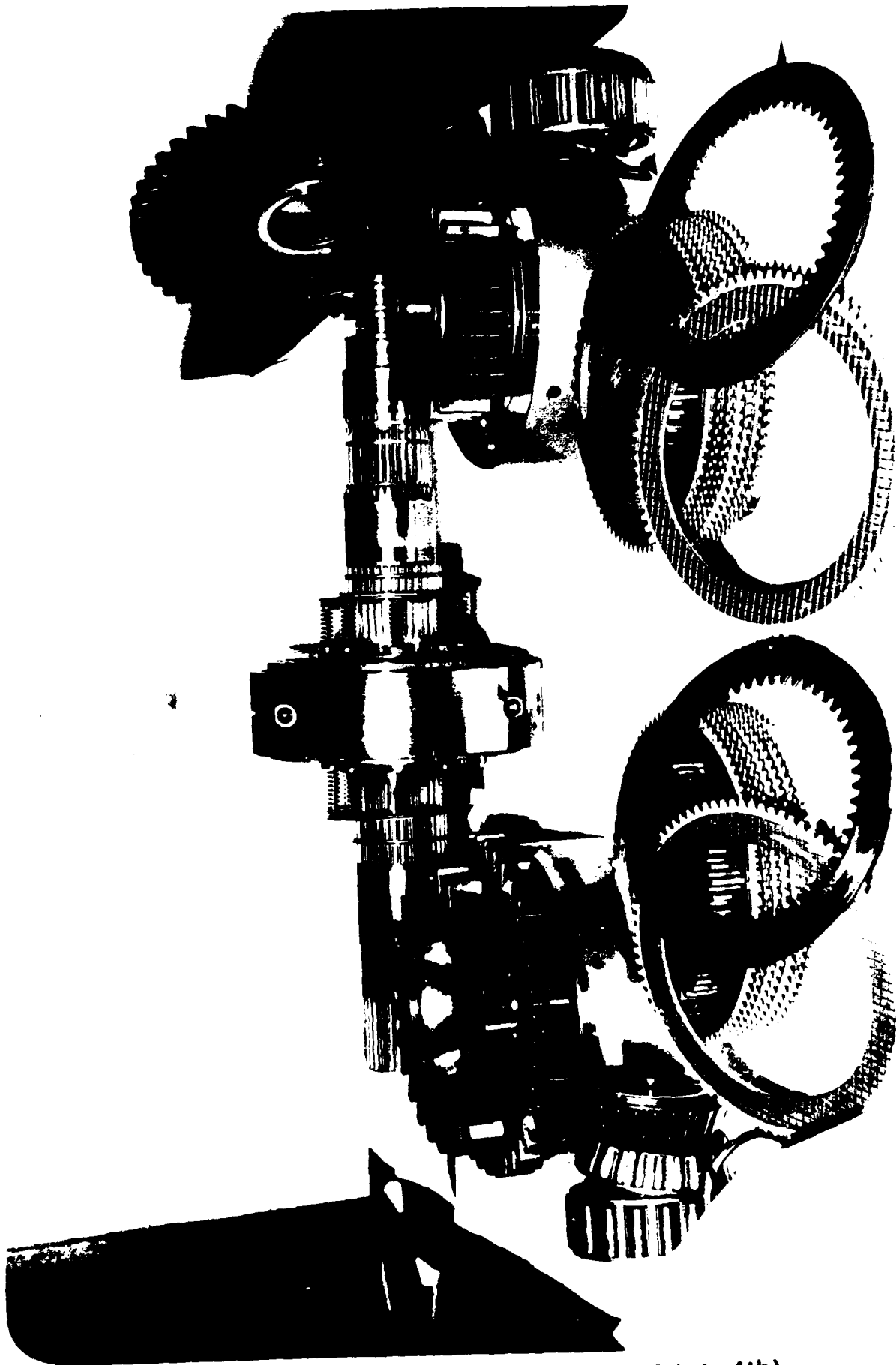
*Bordnick*

Transmission External View

890301E-75



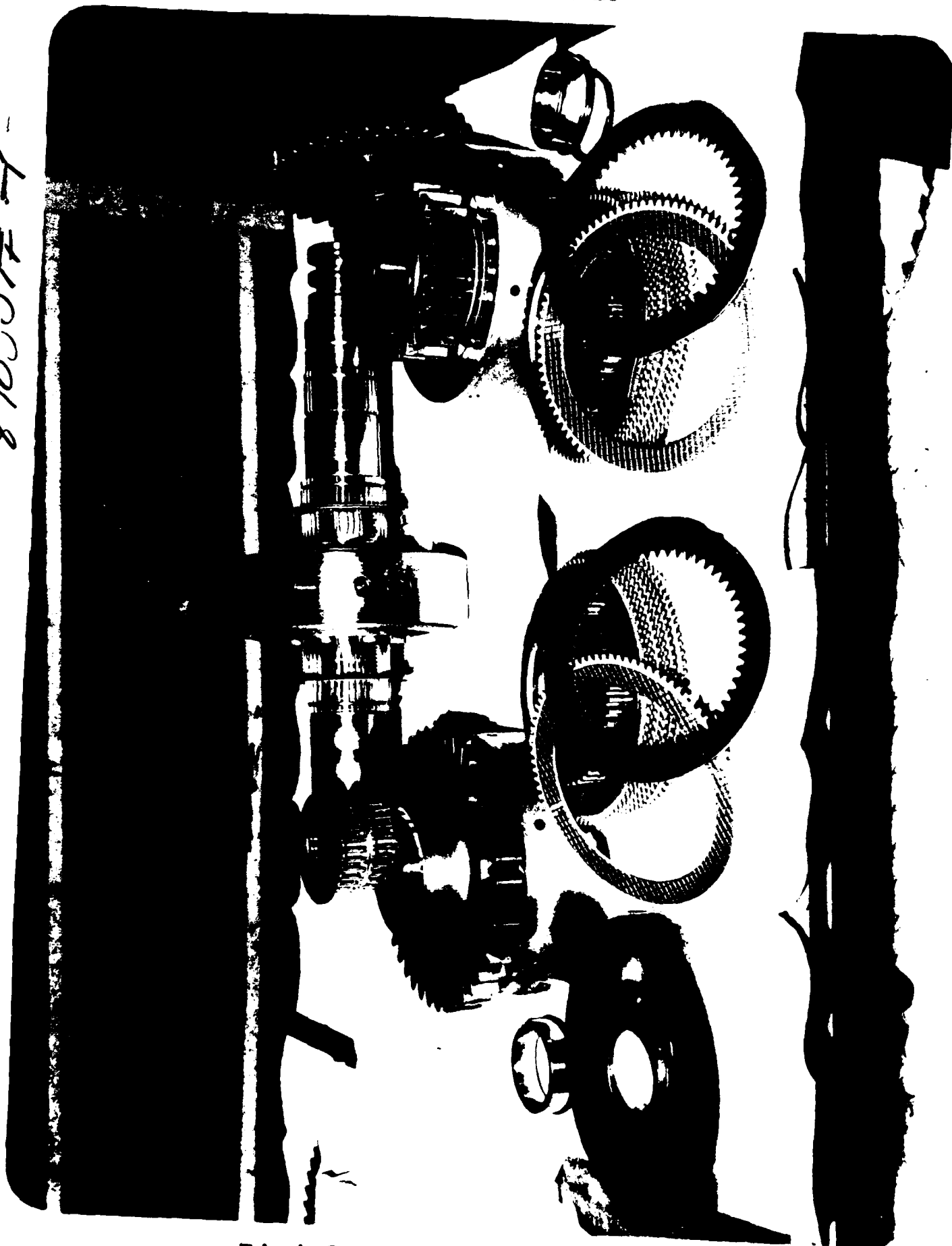
Transmission External View



7-Inch Clutch Pack (2nd, 5th & 1st, 4th)

8705 715 28

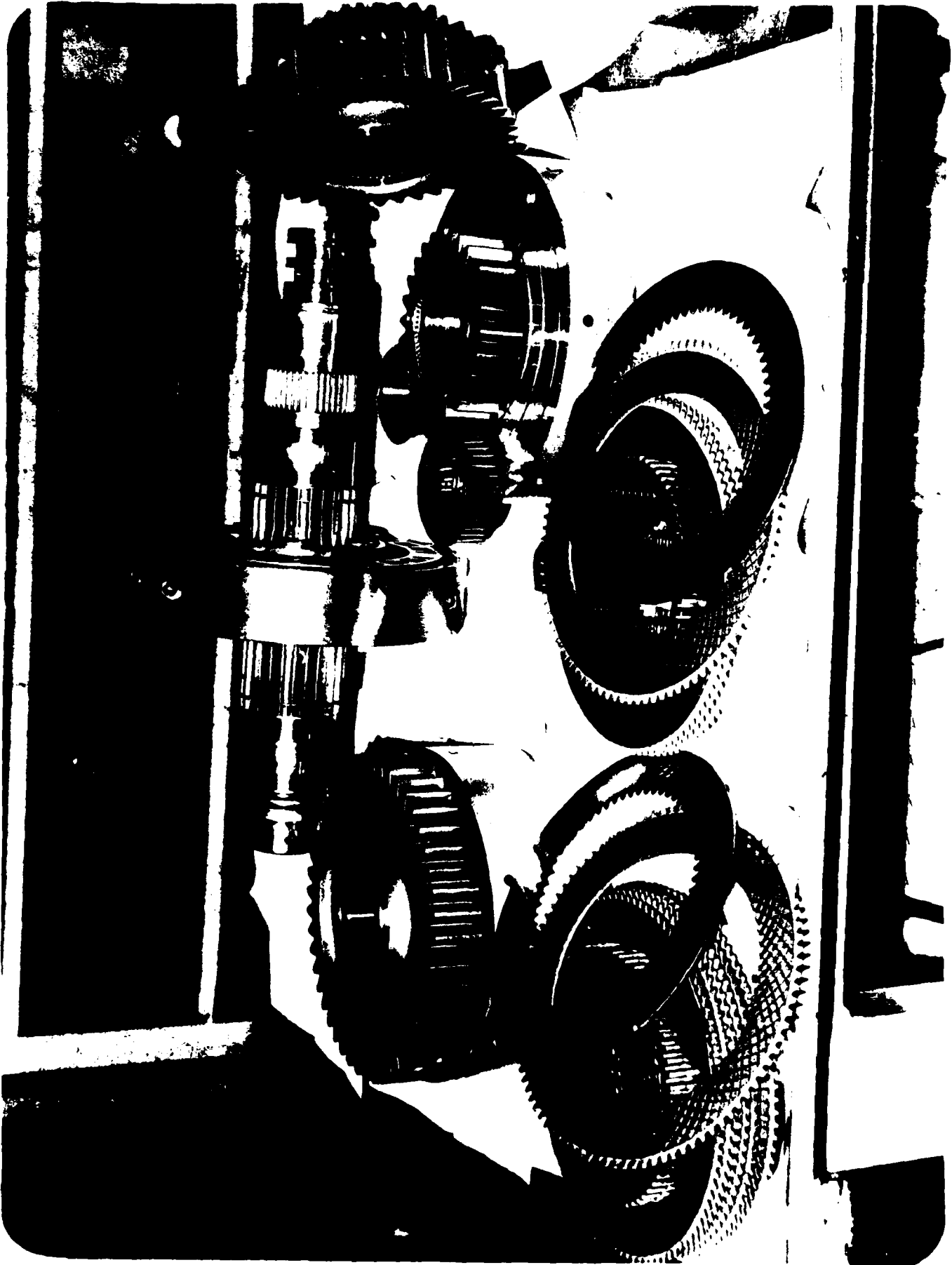
8705097-7



7-Inch Clutch Pack (3rd, 6th & Rev)

PHOTOGRAPH 30

870507E-6



9-Inch Clutch Pack (Rev, 1st, 2nd, 3rd &, 4th, 5th, 6th)

890307E-3



Compound Shaft

*Borden*

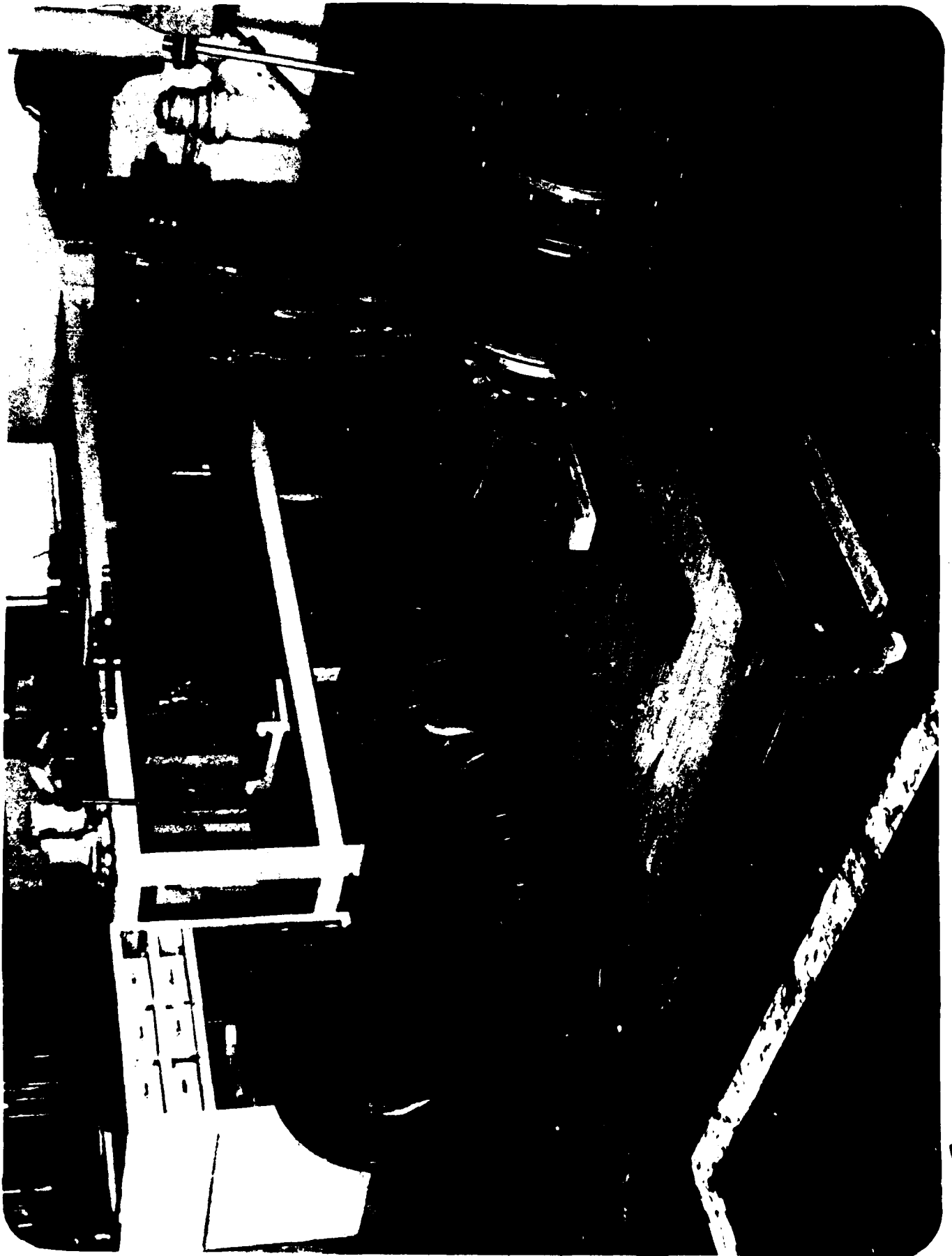


3rd, 6th Clutch Hub Gear Tooth Defect

890507E-15



890506 C-18



*Bordman*

Complete Rear Axle Assembly

## **APPENDIX**

<b>A-1 through A-5</b>	<b>SELECTION OF DRIVELINE COMPONENTS DOCUMENT</b>
<b>A-6 through A-7</b>	<b>COMPONENTRY APPROVAL LETTERS</b>
<b>A-8</b>	<b>LAB ENGINE TORQUE CURVE</b>
<b>A-9 through A-29</b>	<b>FIELD HISTOGRAM DATA</b>
<b>A-30 through A-36</b>	<b>TRANSMISSION POWER FLOW</b>

SELECTION OF DRIVELINE COMPONENTS

for

CONTRACT DAAK70-87-C-0061

Procurement of Testing Services for Self Deployable  
Materials Handling Equipment Drivelines  
from Multiple Sources

Prepared by

Deere & Company  
Moline, Illinois

for

U.S. Army Belvoir R, D & E Center  
Belvoir Procurement Division  
Ft. Belvoir, Virginia

15 October 1987

A-1

A. INTRODUCTION

John Deere assumes that a future 10K SDMHE solicitation will specify most of the requirements for a 10K rough terrain forklift per MIL-T-52843C (1 May 1985), plus the additional requirements of solicitation DAAK70-87-R-0110. After study, John Deere's model 644 loader was selected as the projected machine envelope for these overall requirements. The current production model 644 loader series at 160 engine horsepower can be readily modified to meet the MIL-T-52843C (1 May 1985) requirements. However, the added requirement of high speed transport of the SDMHE requires a power increase to 300 engine horsepower and new driveline components to transmit this increased power at the proper speeds.

B. COMPONENT SELECTIONS

The high speed requirement of the SDMHE is about twice that of present commercial machines. For this reason, the availability of components which will meet SDMHE requirements is limited. This limited availability has necessitated that John Deere's component selections be based upon complete component sets.

John Deere's primary component selections are shown in Table I as Primary Set - 1st Choice. Note that alternate axle and drive shaft components are available within the Primary Set. These are shown in Table I as Primary Set - 2nd Choice.

Table 1

Component	PRIMARY SET (1)	
	1st Choice	2nd Choice
Engine	John Deere 6-619A	John Deere 6-619A
Transmission	Clark Equipment R34683	Clark Equipment R34683
Torque Converter	Clark Equipment CL15.5	Clark Equipment CL15.5
Axle	Rockwell International PRC-676 (13.42 ratio)	Rockwell International PRC676 (13.42 ratio) OR Clark Equipment D33640 (2)
Drive Shaft	Borg-Warner 7C	Borg-Warner 7C OR Rockwell International 72N

(1) Standard Tire Size (20.5 x 25) can be used

(2) This Clark axle is priced 70% (\$2,875 per axle) higher than the Rockwell axle.

John Deere's alternate component selections are shown on Table II as Alternate Set - 1st Choice. Note that alternate engine and drive shaft components are available within the Alternate Set. These are shown in Table II as Alternate Set - 2nd Choice. Note also that the Alternate Set requires a larger than standard tire size (23.5 x 25) to obtain specified ground speeds of the SDMHE.

Table II

Component	ALTERNATE SET (3)	
	1st Choice	2nd Choice
Engine	John Deere 6-619A	John Deere 6-619A OR Cummins LTA-10
Transmission	Twin Disc TD51-11-72 (4)	Twin Disc TD51-11-72 (4)
Torque Converter	Twin Disc 8FLW-1611-1	Twin Disc 8FLW-1611-1
Axle	Rockwell International PRC676 (11.05 ratio)	Rockwell International PRC676 (11.05 ratio)
Drive Shaft	Borg-Warner 7C	Borg-Warner 7C OR Rockwell International 72N

- (3) Requires 23.5 x 25 Tire Size  
(4) The Twin Disc TD51-11-72 is a 5 speed forward - 1 speed reverse power shift transmission.

C. RATIONALE OF PRIMARY COMPONENT SELECTIONS

1. Engine:

The John Deere 6-619A engine is the primary selection. This is a 6 cylinder, 4 cycle, turbocharged and intercooled diesel engine. John Deere has a considerable amount of construction equipment experience with this engine in model 860 scrapers and model 890 excavators. John Deere Engine Engineering has confirmed that this engine will be acceptable for the proposed SDMHE application.

Additional reasons for this engine selection are:

- a. Service parts and service support systems are already in place for this engine.
- b. Various engine accessories required for this application are readily available.
- c. This engine is readily available.
- d. This engine provides the lowest cost installation in the required horsepower range.

2. Transmission:

The Clark Equipment R34683 transmission is the primary selection. This is a 6 speed forward - 3 speed reverse power shift transmission rated by the manufacturer at 300 horsepower. The gear ratios provide for acceptable performance. With properly matched engine, converter, axles, and tires, this transmission provides for the transport requirements without exceeding approved axle input speeds.

Additional reasons for this transmission selection are:

- a. This transmission has helical gearing and will provide quieter operation than a spur gear transmission.
- b. The configuration of the selected transmission provides for remote mounted transmission with engine mounted torque converter. This configuration provides greatest flexibility for mounting of components and also provides for improved serviceability of driveline components.
- c. Cost of this transmission and configuration is greater than some others considered, but the greater cost is more than offset by physical size, configuration, flexibility, serviceability, durability, and reliability considerations.
- d. This transmission is readily available.

3. Torque Converter:

The Clark Equipment CL15.5 torque converter is the primary selection. The manufacturer has used this torque converter successfully in commercial industrial equipment up to 350 horsepower with satisfactory reliability. It fulfills the performance requirements of the 10K SDME when matched with the other primary components selected and coming from the same supplier as the transmission minimizes compatibility related problems.

Additional reasons for this torque converter selection are:

- a. This torque converter provides for automatic clutch lockup eliminating converter slip at transport speed resulting in lower horsepower requirement. NOTE: 40 and 45 mph speeds are the operations requiring the greatest horsepower.
- b. This engine mounted torque converter eliminates the need for a driveline torsional vibration damper.
- c. All parts required for the common hydraulic and converter lockup systems are available.
- d. This torque converter is readily available.

4. Axles:

The Rockwell International PRC 676 (w/13.42 ratio) axle is the primary selection. This axle is assembled from field proven, off-the-shelf components. The gear reduction ratio is compatible with the other primary componentry selected to meet SDMHE performance requirements.

Additional reasons for this axle selection are:

- a. This is a reliable supplier and they have calculated this axle to be acceptable for the intended application.
- b. This is the lowest cost axle studied having the required gear reduction ratio.

5. Drive Shafts:

The Borg-Warner Corporation 7C size universal joints are the primary selections. John Deere presently uses these components in the production model 644 loader with more than adequate life. Engineering calculations indicate they're also acceptable for the high speed applications of the SDMHE. They are readily available and service parts are already set up and available.

D. ALTERNATE COMPONENT SELECTIONS

Alternate components have been selected in case the U.S. Army does not approve the primary components. However, John Deere's study of alternate components has not progressed beyond a preliminary stage. This basically means that component capacities appear adequate and the gear reduction ratios can achieve required ground speeds. Considerable additional design study is required in other areas such as assuring that physical fitup of these components can actually be made.



REPLY TO  
ATTENTION OF

## DEPARTMENT OF THE ARMY

US ARMY BELVOIR RESEARCH, DEVELOPMENT AND ENGINEERING CENTER  
FORT BELVOIR, VIRGINIA 22060-5606

18 NOV 1987

AMSTR-PBLL

Subject: DAAK70-87-C-0061, Selection of Componentry

Deere & Company  
John Deere Road  
Moline, IL 61265-8098

Gentlemen:

In accordance with contractual requirements C.4.2 the contractor is required to obtain the Contracting Officers approval, of the componentry selected for the Self Deployable Material Handling Equipment (SDMHE) Driveline Benchtest before testing can commence.


The components selected by your company for use in performing the driveline benchtesting have been approved by the government. The approved components are as follows:

Engine-JD6-19A  
Transmission-Twin Disc TD51-11-72  
Axle-Rockwell PRC 676  
11.05:1 Ratio

Any deviations from the approved components must be submitted to the contracting officer for his approval prior to incorporation into the driveline benchtest.

If any additional information is required point of contact for this action is Mr. Jennings Cherry telephone (703) 664-5148.

Sincerely,

  
GREGORY C. LANDON  
Contracting Officer





REPLY TO  
ATTENTION OF

DEPARTMENT OF THE ARMY

US ARMY BELVOIR RESEARCH, DEVELOPMENT AND ENGINEERING CENTER  
FORT BELVOIR, VIRGINIA 22060-5606

14 DEC 1987

AMSTR-PBL

Subject: DAAK70-87-C-0061, Selection of Componentry

Deere & Company  
John Deere Road  
Moline, IL 61265-8098

Gentlemen:

Reference: AMSTR-PBL letter dated 18 November 1987 Selection of Componentry.

The purpose of this letter is to revise the components for the Self Deployable Materials Handling Equipment (SDMHE) Driveline Benchtest approved in the above referenced letter to the revised set of components below:

Engine: (Same as previous) JD6-19A


Transmission: Twin Disc TD61-11-71 MOD

Axle: Rockwell PRC 676 Planetary Rigid Axle  
12.726:1 Overall Ratio

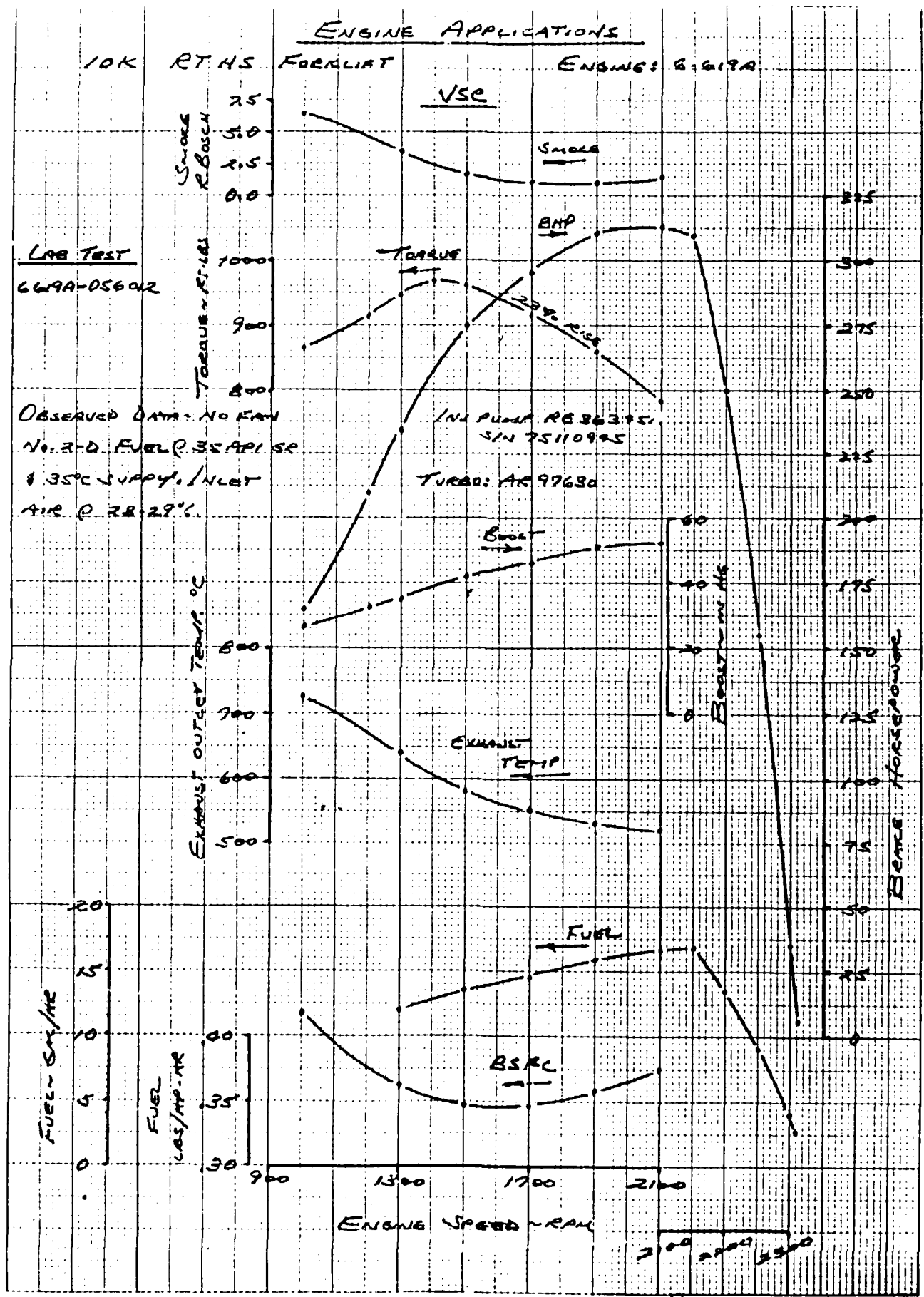
Any deviations from the above listed components must be submitted to the contracting officer for his approval prior to incorporation into the driveline benchtest.

If any additional information is required point of contact for this action is Mr. Jennings Cherry telephone (703) 664-5148.

Sincerely,

  
GREGORY C. LANDON  
Contracting Officer

NO. 345-20 DIETZEN GRAPH PAPER  
20 X 20 PER INCH  
DIETZEN CORPORATION  
MADE IN U.S.A.



1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

OPERATION 1 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 4:52 2JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 0 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: MATERIAL STOCKPILE ON IMPROVED S COMPOSITE %: 0.0; RUN: 7

DATA START TIME: 0.0 SEC.

DATA END TIME: 300.8 SEC.

ITORQ CHN: 4	NAME: FAIT	UNITS: NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL: 8	REF TORQUE: 2000.00	ISPEED I/O RATIO: 1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL: 3	EXPONENT: 5.350	ITORQUE I/O RATIO: 1.00001	

IMIN TORQ (NM): -3760.9	IMIN RPM: 0.0	ISAMPLES/SEC: 1000.000
IMAX TORQ (NM): 3269.2	IMAX RPM: 861.2	ITOTAL REV: 1220.22
IAVE TORQ (NM): 642.7	IAVE RPM: 243.4	IAVE POWER (KW): 16.38

MEAN	REV/HR IN						TOTAL	TOTAL	
TORQUE	GEAR NAMES						IREVOLUTION	DAMAGE	EQUIVALENT
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
3100.	0.1	0.1	0.1	0.1	1.1	0.1	1.11	0.01	10.91
2800.	0.1	0.1	0.1	0.1	1.1	0.1	1.31	0.01	8.01
2500.	0.1	0.1	0.1	0.1	1.1	0.1	1.41	0.01	4.61
2200.	0.1	0.1	0.1	0.1	9.1	0.1	8.51	0.01	11.41
1900.	0.1	0.1	16.1	0.1	46.1	0.1	61.71	0.01	45.61
1600.	0.1	0.1	28.1	0.1	199.1	0.1	226.81	0.01	66.91
1300.	0.1	0.1	234.1	0.1	547.1	0.1	781.91	0.01	72.81
1000.	10.1	1.1	1265.1	0.1	595.1	0.1	1871.51	0.01	48.51
700.	7.1	1.1	868.1	0.1	1536.1	0.1	2412.41	0.01	10.11
400.	2.1	0.1	334.1	0.1	689.1	0.1	1025.01	0.01	0.41
100.	14.1	8.1	1853.1	0.1	831.1	0.1	2706.01	0.01	0.01
-200.	2.1	2.1	925.1	0.1	219.1	0.1	1147.91	0.01	0.01
-500.	2.1	1.1	1299.1	0.1	224.1	0.1	1526.01	0.01	1.61
-800.	27.1	1.1	608.1	0.1	720.1	0.1	1355.71	0.01	12.01
-1100.	14.1	1.1	352.1	0.1	726.1	0.1	1093.21	0.01	43.11
-1400.	6.1	1.1	211.1	0.1	73.1	0.1	290.71	0.01	39.71
-1700.	2.1	1.1	58.1	0.1	0.1	0.1	60.41	0.01	22.11
-2000.	1.1	1.1	10.1	0.1	0.1	0.1	12.51	0.01	12.91
-2300.	0.1	1.1	11.1	0.1	0.1	0.1	12.21	0.01	22.21
-2600.	0.1	1.1	1.1	0.1	0.1	0.1	2.51	0.01	10.21
-2900.	0.1	1.1	1.1	0.1	0.1	0.1	2.41	0.01	17.71
-3200.	0.1	1.1	1.1	0.1	0.1	0.1	1.51	0.01	19.01
-3500.	0.1	1.1	0.1	0.1	0.1	0.1	1.51	0.01	29.71
-3800.	0.1	0.1	0.1	0.1	0.1	0.1	0.31	0.01	7.71
TOTAL	88.1	23.1	8077.1	0.1	6416.1	0.1	14604.41		
DAMAGE	11.1	54.1	204.1	0.1	248.1	0.1			517.01

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

# OPERATION 1- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 4:52 2JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 0 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: MATERIAL STOCKPILE ON IMPROVED S COMPOSITE %: 0.0; RUN: 7

DATA START TIME: 0.0 SEC.

DATA END TIME: 300.8 SEC.

ITORQ CHN:	5	NAME :	RAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	REF TORQUE:	2000.00	SPEED I/O RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	TORQUE I/O RATIO:	1.0000	

IMIN TORQ (NM) :	-3388.4	IMIN RPM:	0.0	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM) :	2244.7	IMAX RPM:	861.2	ITOTAL REV:	1220.22
IAVE TORQ (NM) :	784.8	IAVE RPM:	243.4	IAVE POWER (KW):	20.00

MEAN	REV/HR IN					TOTAL	TOTAL	
TORQUE	GEAR NAMES					REVOLUTION	DAMAGE	EQUIVALENT
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR
2000.	4.1	0.1	0.1	0.1	27.1	0.1	31.11	0.01
1700.	21.1	0.1	1.1	0.1	291.1	0.1	313.01	0.01
1400.	9.1	0.1	1.1	0.1	569.1	0.1	578.81	0.01
1100.	9.1	0.1	1.1	0.1	1065.1	0.1	1075.21	0.01
800.	0.1	0.1	1.1	0.1	1536.1	0.1	1537.21	0.01
500.	10.1	1.1	12.1	0.1	1213.1	0.1	1235.81	0.01
200.	7.1	1.1	126.1	0.1	692.1	0.1	825.71	0.01
-100.	14.1	8.1	1297.1	0.1	642.1	0.1	1961.61	0.01
-400.	1.1	2.1	1596.1	0.1	202.1	0.1	1801.01	0.01
-700.	2.1	1.1	3396.1	0.4	116.1	0.1	3513.41	0.01
-1000.	2.1	1.1	834.1	0.1	49.1	0.1	887.41	0.01
-1300.	2.1	2.1	519.1	0.1	14.1	0.1	536.01	0.01
-1600.	2.1	1.1	246.1	0.1	0.1	0.1	249.21	0.01
-1900.	1.1	1.1	44.1	0.1	0.1	0.1	46.41	0.01
-2200.	1.1	1.1	3.1	0.1	0.1	0.1	5.11	0.01
-2500.	1.1	1.1	2.1	0.1	0.1	0.1	3.01	0.01
-2800.	0.1	1.1	0.1	0.1	0.1	0.1	1.21	0.01
-3100.	0.1	1.1	0.1	0.1	0.1	0.1	1.61	0.01
-3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.41	0.01
TOTAL	88.1	23.1	8077.1	0.1	6415.1	0.1	14604.41	
DAMAGE	27.1	31.1	197.1	0.1	280.1	0.1		533.21

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

# OPERATION 2 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 0:21 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 4 MIN 59 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: MATERIAL HANDLING ON UNIMPROVED S COMPOSITE %: 0.0; RUN: 8

DATA START TIME: 0.0 SEC.

DATA END TIME: 299.4 SEC.

ITORQ CHN:	4	INAME :	FAIT	IUNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/D RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/D RATIO:	1.0000	
IMIN TORQ (NM ):	-3027.8	IMIN RPM:	0.0	ISAMPLES/SEC:	1000.000	
IMAX TORQ (NM ):	2761.3	IMAX RPM:	543.6	ITOTAL REV:	903.99	
IAVE TORQ (NM ):	539.7	IAVE RPM:	181.1	IAVE POWER (KW):	10.24	

MEAN	REV/HR IN				TOTAL		TOTAL	
TORQUE	GEAR NAMES				REVISION	DAMAGE	EQUIVALENT	
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR
2800.	0.1	0.1	0.1	0.1	0.1	0.1	0.21	0.01
2500.	0.1	0.1	0.1	0.1	13.1	0.1	13.01	0.01
2200.	0.1	0.1	0.1	0.1	28.1	0.1	27.51	0.01
1900.	0.1	0.1	0.1	0.1	72.1	0.1	72.21	0.01
1600.	0.1	0.1	0.1	0.1	102.1	0.1	101.71	0.01
1300.	0.1	1.1	0.1	0.1	192.1	0.1	193.21	0.01
1000.	1.1	123.1	0.1	0.1	393.1	0.1	517.41	0.01
700.	0.1	333.1	0.1	0.1	637.1	0.1	970.01	0.01
400.	3.1	343.1	0.1	0.1	631.1	0.1	976.71	0.01
100.	24.1	1060.1	0.1	0.1	1140.1	0.1	2224.21	0.01
-200.	5.1	1325.1	0.1	0.1	447.1	0.1	1776.61	0.01
-500.	3.1	1424.1	0.1	0.1	430.1	0.1	1857.51	0.01
-800.	3.1	1190.1	0.1	0.1	124.1	0.1	1316.81	0.01
-1100.	0.1	476.1	0.1	0.1	0.1	0.1	476.71	0.01
-1400.	0.1	169.1	0.1	0.1	0.1	0.1	168.71	0.01
-1700.	0.1	106.1	0.1	0.1	0.1	0.1	105.51	0.01
-2000.	0.1	69.1	0.1	0.1	0.1	0.1	69.01	0.01
-2300.	0.1	3.1	0.1	0.1	0.1	0.1	2.51	0.01
-2600.	0.1	1.1	0.1	0.1	0.1	0.1	0.61	0.01
-2900.	0.1	1.1	0.1	0.1	0.1	0.1	0.51	0.01
TOTAL	39.1	6623.1	0.1	0.1	4209.1	0.1	10869.01	
DAMAGE	0.1	181.1	0.1	0.1	203.1	0.1		384.41

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

# OPERATION 2 - REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 0:21 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 4 MIN 59 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: MATERIAL HANDLING ON UNIMPROVED S COMPOSITE %: 0.0; RUN: 8

DATA START TIME: 0.0 SEC.

DATA END TIME: 299.4 SEC.

ITORQ CHN:	5	NAME :	RAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	REF TORQUE:	2000.00	ISPEED I/O RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	ITORQUE I/O RATIO:	1.0000	

IMIN TORQ (NM ):	-2546.1	IMIN RPM:	0.0	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	2096.2	IMAX RPM:	543.6	ITOTAL REV:	903.99
IAVE TORQ (NM ):	575.4	IAVE RPM:	181.1	IAVE POWER (KW):	10.91

MEAN	REV/HR IN					TOTAL	TOTAL	
TORQUE	GEAR NAMES					IREVOLUTION	DAMAGE	EQUIVALENT
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR
2000.	0.1	0.1	0.1	0.1	1.1	0.1	0.51	0.01
1700.	0.1	0.1	0.1	0.1	2.1	0.1	2.11	0.01
1400.	2.1	0.1	0.1	0.1	12.1	0.1	13.31	0.01
1100.	3.1	0.1	0.1	0.1	215.1	0.1	218.21	0.01
800.	3.1	2.1	0.1	0.1	857.1	0.1	862.61	0.01
500.	6.1	39.1	0.1	0.1	1647.1	0.1	1691.61	0.01
200.	5.1	142.1	0.1	0.1	883.1	0.1	1030.21	0.01
-100.	17.1	1896.1	0.1	0.1	489.1	0.1	2402.11	0.01
-400.	1.1	2184.1	0.1	0.1	71.1	0.1	2255.81	0.01
-700.	1.1	1605.1	0.1	0.1	28.1	0.1	1633.61	0.01
-1000.	1.1	576.1	0.1	0.1	4.1	0.1	580.61	0.01
-1300.	0.1	142.1	0.1	0.1	0.1	0.1	142.81	0.01
-1600.	0.1	27.1	0.1	0.1	0.1	0.1	27.61	0.01
-1900.	0.1	6.1	0.1	0.1	0.1	0.1	6.11	0.01
-2200.	0.1	3.1	0.1	0.1	0.1	0.1	3.21	0.01
-2500.	0.1	1.1	0.1	0.1	0.1	0.1	0.71	0.01
TOTAL	39.1	6623.1	0.1	0.1	4209.1	0.1	10869.01	
DAMAGE	1.1	51.1	0.1	0.1	17.1	0.1		68.81

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1 PAGE: 10F 2; TABLE:-----

# OPERATION 3 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE EIR: .  
 FILE NAME: T1FORKL DATE: 1:27 6JUL88  
 ENGINEER: BORDEWICK RUN TIME: 5 MIN 52 SEC  
 CONDITIONS: HOT DRY TEST: LOW SPEED TORQUE HISTORY  
 OPERATION: MAERIAL HANDLING ON BEACH SAND COMPOSITE %: 0.0; RUN: 18  
 DATA START TIME: 0.0 SEC. DATA END TIME: 352.7 SEC.

ITRQ CHN: 4 INAME : FAIT IUNITS: NM I DAMAGE CALCULATED USING:  
 ICOMMAND CHANNEL: 8 IREF TORQUE: 2000.00 ISPEED I/O RATIO: 1.00001 TORQUE AT EACH DATA POINT  
 ISPEED CHANNEL: 3 IEXPONENT: 5.350 ITORQUE I/O RATIO: 1.00001

IMIN TORQ (NM ): -5664.5 IMIN RPM: 0.0 ISAMPLES/SEC: 1000.000 I  
 IMAX TORQ (NM ): 7431.8 IMAX RPM: 595.6 ITOTAL REV: - 1284.07 I  
 IAVE TORQ (NM ): 1953.2 IAVE RPM: 218.5 IAVE POWER (KW): 44.68 I

MEAN	REV/HR IN					TOTAL	TOTAL
TORQUE	GEAR NAMES					IREVOLUTIONI	DAMAGE IEQUIVALENTI
LEVEL	NEUT	1F	2F	3F	1R	UNKN PER HOUR	FACTOR DAMAGE
7300.	0.1	0.1	0.1	0.1	1.1	0.1	0.01 740.91
7000.	0.1	0.1	0.1	0.1	1.1	0.1	0.01 1039.61
6700.	0.1	0.1	0.1	0.1	2.1	0.1	0.01 1415.61
6400.	0.1	0.1	0.1	0.1	35.1	0.1	0.01 17017.41
6100.	0.1	0.1	0.1	0.1	43.1	0.1	0.01 16769.61
5800.	0.1	0.1	0.1	0.1	19.1	0.1	0.01 5732.91
5500.	0.1	0.1	0.1	0.1	22.1	0.1	0.01 5046.31
5200.	0.1	0.1	0.1	0.1	10.1	0.1	0.01 1656.61
4900.	0.1	0.1	0.1	0.1	10.1	0.1	0.01 1256.61
4600.	0.1	0.1	0.1	0.1	25.1	0.1	0.01 1990.21
4300.	0.1	0.1	0.1	0.1	18.1	0.1	0.01 1164.51
4000.	0.1	0.1	0.1	0.1	10.1	0.1	0.01 373.01
3700.	0.1	0.1	0.1	0.1	31.1	0.1	0.01 816.31
3400.	0.1	0.1	0.1	0.1	86.1	0.1	0.01 1504.21
3100.	0.1	0.1	0.1	0.1	90.1	0.1	0.01 937.21
2800.	0.1	0.1	0.1	0.1	87.1	0.1	0.01 530.91
2500.	0.1	0.1	0.1	0.1	107.1	0.1	0.01 357.51
2200.	0.1	0.1	0.1	0.1	356.1	0.1	0.01 568.71
1900.	0.1	0.1	0.1	0.1	492.1	0.1	0.01 385.11
1600.	0.1	0.1	0.1	0.1	565.1	0.1	0.01 171.01
1300.	0.1	0.1	0.1	0.1	547.1	0.1	0.01 59.41
1000.	2.1	0.1	0.1	0.1	501.1	0.1	0.01 15.21
700.	4.1	12.1	0.1	0.1	198.1	0.1	0.01 0.91
400.	1.1	46.1	0.1	0.1	132.1	0.1	0.01 0.11
100.	12.1	326.1	0.1	0.1	187.1	0.1	0.01 0.01
-200.	3.1	333.1	0.1	0.1	5.1	0.1	0.01 0.01
-500.	3.1	607.1	0.1	0.1	2.1	0.1	0.01 0.61
-800.	0.1	836.1	0.1	0.1	1.1	0.1	0.01 6.81
-1100.	1.1	796.1	0.1	0.1	0.1	0.1	0.01 36.21
-1400.	1.1	793.1	0.1	0.1	0.1	0.1	0.01 123.11

\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \* PAGE: 20F 2; TABLE: \_\_\_\_\_

# OPERATION 3 - FRONT AXLE INPUT SHAFT (CONT'D)

MACHINE: SDMHE EIR: .  
 FILE NAME: T1FORKL DATE: 1:27 6JUL88  
 ENGINEER: BORDEWICK RUN TIME: 5 MIN 52 SEC  
 CONDITIONS: HOT DRY TEST: LOW SPEED TORQUE HISTORY  
 OPERATION: MAERIAL HANDLING ON BEACH SAND COMPOSITE %: 0.0; RUN: 18  
 DATA START TIME: 0.0 SEC. DATA END TIME: 352.7 SEC.

ITORD CHN: 4 INAME : FAIT IUNITS: NM

MEAN TORQUE LEVEL	NEUT	1F	2F	3F	1R	UNKN	TOTAL REVOLUTION PER HOUR	DAMAGE FACTOR	TOTAL EQUIVALENT DAMAGE
-1700.	0.1	765.1	0.1	0.1	0.1	0.1	764.81	0.01	324.11
-2000.	0.1	623.1	0.1	0.1	0.1	0.1	622.91	0.01	608.31
-2300.	0.1	427.1	0.1	0.1	0.1	0.1	427.41	0.01	913.01
-2600.	0.1	427.1	0.1	0.1	0.1	0.1	427.21	0.01	1797.61
-2900.	0.1	653.1	0.1	0.1	0.1	0.1	653.11	0.01	4893.51
-3200.	0.1	788.1	0.1	0.1	0.1	0.1	788.01	0.01	9710.61
-3500.	0.1	445.1	0.1	0.1	0.1	0.1	444.91	0.01	8769.31
-3800.	0.1	340.1	0.1	0.1	0.1	0.1	339.81	0.01	10575.11
-4100.	0.1	223.1	0.1	0.1	0.1	0.1	223.31	0.01	10498.01
-4400.	0.1	276.1	0.1	0.1	0.1	0.1	276.31	0.01	19148.61
-4700.	0.1	459.1	0.1	0.1	0.1	0.1	458.91	0.01	44500.91
-5000.	0.1	250.1	0.1	0.1	0.1	0.1	249.81	0.01	32931.51
-5300.	0.1	69.1	0.1	0.1	0.1	0.1	68.81	0.01	12041.21
-5600.	0.1	2.1	0.1	0.1	0.1	0.1	2.31	0.01	530.01
TOTAL	27.1	9497.1	0.1	0.1	3584.1	0.1	13107.51		
DAMAGE	0.1157385.1		0.1	0.1	59545.1	0.1			216958.11



1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

# OPERATION 3 - REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:27 6JUL88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 52 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: MAERIAL HANDLING ON BEACH SAND COMPOSITE %: 0.0; RUN: 18

DATA START TIME: 0.0 SEC.

DATA END TIME: 352.7 SEC.

ITORD CHN:	5	INAME :	RAIT	IUNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001	

IMIN TORQ (NM ):	-3320.0	IMIN RPM:	0.0	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	2429.7	IMAX RPM:	595.6	ITOTAL REV:	1284.07
IAVE TORQ (NM ):	928.2	IAVE RPM:	218.5	IAVE POWER (KW):	21.23

MEAN TORQUE LEVEL	NEUT	1F	2F	3F	1R	UNKN	TOTAL REVOLUTION PER HOUR	DAMAGE FACTOR	TOTAL EQUIVALENT DAMAGE
2300.	0.1	0.1	0.1	0.1	1.1	0.1	1.21	0.01	2.41
2000.	0.1	0.1	0.1	0.1	2.1	0.1	1.91	0.01	2.01
1700.	0.1	0.1	0.1	0.1	9.1	0.1	8.51	0.01	3.71
1400.	0.1	0.1	0.1	0.1	15.1	0.1	15.51	0.01	2.11
1100.	0.1	0.1	0.1	0.1	204.1	0.1	204.71	0.01	6.91
800.	3.1	0.1	0.1	0.1	769.1	0.1	771.71	0.01	6.41
500.	4.1	0.1	0.1	0.1	1379.1	0.1	1382.61	0.01	1.01
200.	5.1	3.1	0.1	0.1	1051.1	0.1	1058.11	0.01	0.01
-100.	13.1	531.1	0.1	0.1	147.1	0.1	689.81	0.01	0.01
-400.	1.1	1671.1	0.1	0.1	7.1	0.1	1678.81	0.01	0.61
-700.	1.1	2067.1	0.1	0.1	0.1	0.1	2068.51	0.01	8.41
-1000.	1.1	1604.1	0.1	0.1	0.1	0.1	1604.61	0.01	38.91
-1300.	0.1	1102.1	0.1	0.1	0.1	0.1	1102.31	0.01	112.91
-1600.	0.1	687.1	0.1	0.1	0.1	0.1	686.91	0.01	204.21
-1900.	0.1	512.1	0.1	0.1	0.1	0.1	511.61	0.01	390.51
-2200.	0.1	481.1	0.1	0.1	0.1	0.1	480.71	0.01	838.81
-2500.	0.1	557.1	0.1	0.1	0.1	0.1	557.31	0.01	1838.71
-2800.	0.1	266.1	0.1	0.1	0.1	0.1	265.71	0.01	1507.91
-3100.	0.1	17.1	0.1	0.1	0.1	0.1	17.11	0.01	159.31
-3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.41	0.01	5.11
TOTAL	27.1	9497.1	0.1	0.1	3584.1	0.1	13107.51		
DAMAGE	0.1	5104.1	0.1	0.1	24.1	0.1			5129.71

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL #1

PAGE: 10F 1; TABLE:-----

OPERATION 4 - FRONT AXLE INPUT SHAFT

MACHINE: SDMH2

EIR: .

FILE NAME: T1FORKL

DATE: 1:08 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 2 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 12

DATA START TIME: 0.0 SEC.

DATA END TIME: 302.2 SEC.

ITORQ CHN:	4	NAME :	FAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001	

IMIN TORQ (NM) :	-2863.8	IMIN RPM:	3.1	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM) :	3541.5	IMAX RPM:	750.3	ITOTAL REV:	1723.67
IAVE TORQ (NM) :	480.2	IAVE RPM:	342.2	IAVE POWER (KW):	17.20

MEAN TORQUE LEVEL	REV/HR IN GEAR NAMES						TOTAL REVOLUTION PER HOUR	TOTAL DAMAGE FACTOR	TOTAL EQUIVALENT DAMAGE
	NEUT	1F	2F	3F	1R	UNKN			
3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.21	0.01	3.41
3100.	0.1	0.1	0.1	0.1	0.1	0.1	0.31	0.01	2.81
2800.	0.1	0.1	0.1	0.1	1.1	0.1	0.91	0.01	5.21
2500.	0.1	0.1	0.1	0.1	1.1	0.1	0.91	0.01	2.71
2200.	0.1	0.1	0.1	0.1	1.1	0.1	1.31	0.01	2.01
1900.	0.1	0.1	0.1	0.1	16.1	0.1	16.11	0.01	10.31
1600.	0.1	0.1	0.1	0.1	65.1	0.1	65.11	0.01	20.01
1300.	2.1	0.1	88.1	0.1	112.1	0.1	201.91	0.01	16.81
1000.	5.1	1.1	533.1	0.1	273.1	0.1	811.01	0.01	17.91
700.	4.1	1.1	1931.1	0.1	1122.1	0.1	3057.61	0.01	10.51
400.	6.1	2.1	4854.1	0.1	936.1	0.1	5797.11	0.01	1.61
100.	22.1	13.1	4897.1	0.1	1275.1	0.1	6206.41	0.01	0.01
-200.	1.1	4.1	799.1	0.1	544.1	0.1	1348.31	0.01	0.01
-500.	1.1	2.1	770.1	0.1	240.1	0.1	1013.71	0.01	0.91
-800.	1.1	1.1	650.1	0.1	134.1	0.1	786.31	0.01	5.81
-1100.	0.1	1.1	703.1	0.1	0.1	0.1	705.41	0.01	28.71
-1400.	0.1	1.1	272.1	0.1	0.1	0.1	274.01	0.01	39.31
-1700.	1.1	2.1	138.1	0.1	0.1	0.1	139.81	0.01	56.11
-2000.	0.1	1.1	43.1	0.1	0.1	0.1	44.61	0.01	41.81
-2300.	0.1	1.1	25.1	0.1	0.1	0.1	26.11	0.01	56.11
-2600.	0.1	0.1	24.1	0.1	0.1	0.1	23.91	0.01	98.21
-2900.	0.1	0.1	5.1	0.1	0.1	0.1	5.41	0.01	32.51
TOTAL	43.1	31.1	15731.1	0.1	4721.1	0.1	20525.61		
DAMAGE	1.1	3.1	381.1	0.1	68.1	0.1			452.71

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_ \_

# OPERATION 4- REAR AXLE INPUT SHAFT

MACHINE: SUMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:08 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 2 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 12

DATA START TIME: 0.0 SEC.

DATA END TIME: 302.2 SEC.

ITORD CHN:	5	NAME :	RAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001	

IMIN TORQ (NM ):	-3268.0	IMIN RPM:	3.1	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	2001.8	IMAX RPM:	750.3	ITOTAL REV:	1723.67
IAVE TORQ (NM ):	599.2	IAVE RPM:	342.2	IAVE POWER (KW):	21.47

MEAN	REV/HR IN						TOTAL	TOTAL	
TORQUE	GEAR NAMES						(REVOLUTION)	DAMAGE	(EQUIVALENT)
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
1700.	0.1	0.1	0.1	0.1	45.1	0.1r	44.81	0.01	17.71
1400.	0.1	0.1	0.1	0.1	45.1	0.1	44.81	0.01	6.81
1100.	0.1	0.1	0.1	0.1	168.1	0.1	167.71	0.01	5.81
800.	0.1	0.1	11.1	0.1	1221.1	0.1	1232.51	0.01	7.91
500.	3.1	0.1	64.1	0.1	1446.1	0.1	1513.21	0.01	1.31
200.	2.1	0.1	195.1	0.1	763.1	0.1	960.11	0.01	0.01
-100.	25.1	7.1	1358.1	0.1	794.1	0.1	2184.21	0.01	0.01
-400.	6.1	3.1	4504.1	0.1	126.1	0.1	4638.51	0.01	1.81
-700.	2.1	3.1	7663.1	0.1	73.1	0.1	7740.31	0.01	28.71
-1000.	1.1	3.1	1597.1	0.1	26.1	0.1	1627.31	0.01	33.21
-1300.	1.1	3.1	277.1	0.1	11.1	0.1	292.31	0.01	24.71
-1600.	1.1	2.1	33.1	0.1	0.1	0.1	36.31	0.01	10.91
-1900.	1.1	2.1	23.1	0.1	0.1	0.1	25.71	0.01	20.21
-2200.	1.1	3.1	6.1	0.1	0.1	0.1	10.01	0.01	15.31
-2500.	0.1	2.1	0.1	0.1	0.1	0.1	2.21	0.01	6.91
-2800.	0.1	2.1	0.1	0.1	0.1	0.1	2.11	0.01	11.91
-3100.	0.1	0.1	0.1	0.1	0.1	0.1	0.51	0.01	5.11
-3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.01	0.41
TOTAL	43.1	31.1	15731.1	0.1	4718.1	0.1	20525.61		
DAMAGE	3.1	30.1	124.1	0.1	44.1	0.1			198.71

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL #1

PAGE: 10F 1; TABLE:-----

OPERATION 4 - FRONT AXLE INPUT SHAFT

MACHINE: SDME

EIR: .

FILE NAME: T1FORKL

DATE: 1:16 6JUN38

ENGINEER: BORDEWICK

RUN TIME: 4 MIN 54 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 13

DATA START TIME: 0.0 SEC.

DATA END TIME: 294.5 SEC.

ITORD CHN: 4 INAME: FAIT IUNITS: NM I DAMAGE CALCULATED USING:  
ICOMMAND CHANNEL: 8 IREF TORQUE: 2000.00 ISPEED I/O RATIO: 1.00001 TORQUE AT EACH DATA POINT  
ISPEED CHANNEL: 3 IEXPONENT: 5.350 ITORQUE I/O RATIO: 1.00001

IMIN TORQ (NM) : -2993.8 IMIN RPM: 3.1 ISAMPLES/SEC: 1000.000 I  
IMAX TORQ (NM) : 3388.9 IMAX RPM: 1106.0 ITOTAL REV: 1740.81 I  
IAVE TORQ (NM) : 532.1 IAVE RPM: 354.6 IAVE POWER (KW): 19.76 I

MEAN	REV/HR IN						TOTAL	TOTAL	
TORQUE	GEAR NAMES						IREVOLUTION	DAMAGE	EQUIVALENT
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	1.31
3100.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	3.31
2800.	0.1	0.1	0.1	0.1	1.1	0.1	0.71	0.01	4.01
2500.	0.1	0.1	0.1	0.1	2.1	0.1	1.71	0.01	5.71
2200.	0.1	0.1	0.1	0.1	3.1	0.1	2.51	0.01	4.31
1900.	0.1	0.1	0.1	0.1	17.1	0.1	17.31	0.01	10.91
1600.	0.1	0.1	0.1	0.1	62.1	0.1	62.31	0.01	18.61
1300.	1.1	0.1	0.1	180.1	198.1	0.1	379.81	0.01	31.01
1000.	3.1	1.1	1.1	1861.1	406.1	0.1	2271.81	0.01	54.91
700.	16.1	1.1	2.1	967.1	1207.1	0.1	2192.51	0.01	8.61
400.	9.1	3.1	2.1	2615.1	971.1	0.1	3599.91	0.01	0.91
100.	29.1	19.1	12.1	5745.1	1168.1	0.1	6973.31	0.01	0.01
-200.	1.1	4.1	5.1	691.1	358.1	0.1	1060.11	0.01	0.01
-500.	1.1	2.1	8.1	1201.1	291.1	0.1	1503.61	0.01	1.31
-800.	1.1	3.1	4.1	1136.1	94.1	0.1	1238.41	0.01	8.91
-1100.	1.1	2.1	3.1	1134.1	10.1	0.1	1151.11	0.01	49.11
-1400.	1.1	2.1	3.1	487.1	0.1	0.1	492.31	0.01	69.41
-1700.	0.1	1.1	1.1	127.1	0.1	0.1	130.61	0.01	53.81
-2000.	0.1	1.1	1.1	86.1	0.1	0.1	88.21	0.01	88.91
-2300.	0.1	1.1	0.1	56.1	0.1	0.1	57.51	0.01	124.01
-2600.	0.1	0.1	0.1	37.1	0.1	0.1	37.11	0.01	142.71
-2900.	0.1	0.1	0.1	11.1	0.1	0.1	11.01	0.01	76.31
TOTAL	64.1	41.1	43.1	16336.1	4788.1	0.1	21277.81		
DAMAGE	1.1	5.1	3.1	667.1	82.1	0.1			757.81

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

# OPERATION 4- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:16 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 4 MIN 54 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 13

DATA START TIME: 0.0 SEC.

DATA END TIME: 294.5 SEC.

ITORQ CHN:	5	INAME :	RAIT	IUNITS:	NH	I	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001		TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001		

IMIN TORQ (NH ):	-3313.0	IMIN RPM:	3.1	ISAMPLES/SEC:	1000.000	I	
IMAX TORQ (NH ):	1927.5	IMAX RPM:	1106.0	ITOTAL REV:	1740.81	I	
IAVE TORQ (NH ):	645.1	IAVE RPM:	354.6	IAVE POWER (KW):	23.96	I	

MEAN	REV/HR IN					TOTAL	TOTAL		
TORQUE	GEAR NAMES					IREVOLUTION	DAMAGE	EQUIVALENT	
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
1700.	0.1	0.1	0.1	0.1	50.1	0.1	50.41	0.01	19.91
1400.	0.1	0.1	0.1	0.1	37.1	0.1	37.41	0.01	6.21
1100.	0.1	0.1	0.1	0.1	166.1	0.1	166.41	0.01	5.81
800.	0.1	0.1	0.1	11.1	1012.1	0.1	1023.41	0.01	7.11
500.	6.1	0.1	0.1	28.1	1847.1	0.1	1881.71	0.01	1.51
200.	9.1	0.1	1.1	110.1	869.1	0.1	988.91	0.01	0.01
-100.	34.1	12.1	9.1	1154.1	545.1	0.1	1753.51	0.01	0.01
-400.	3.1	6.1	5.1	3490.1	148.1	0.1	3651.71	0.01	1.41
-700.	3.1	4.1	7.1	6999.1	91.1	0.1	7105.31	0.01	28.61
-1000.	3.1	3.1	5.1	3078.1	18.1	0.1	3107.31	0.01	71.31
-1300.	2.1	3.1	4.1	1320.1	0.1	0.1	1330.01	0.01	121.71
-1600.	1.1	4.1	4.1	137.1	0.1	0.1	146.61	0.01	38.41
-1900.	1.1	3.1	3.1	7.1	0.1	0.1	14.61	0.01	10.71
-2200.	1.1	2.1	2.1	0.1	0.1	0.1	4.91	0.01	8.11
-2500.	1.1	2.1	1.1	0.1	0.1	0.1	3.21	0.01	10.61
-2800.	0.1	2.1	1.1	0.1	0.1	0.1	2.91	0.01	18.41
-3100.	1.1	0.1	0.1	0.1	0.1	0.1	1.31	0.01	13.61
-3400.	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.01	1.41
TOTAL	64.1	41.1	43.1	16336.1	4786.1	0.1	21277.81		
DAMAGE	14.1	28.1	19.1	262.1	43.1	0.1			364.61

\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

# OPERATION 5-FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:00 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 5 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 11

DATA START TIME: 0.0 SEC.

DATA END TIME: 305.6 SEC.

ITORQ CHN:	4	INAME :	FAIT	IUNITS:	NH	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001	

IMIN TORQ (NM ):	-2273.0	IMIN RPM:	1.9	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	3055.3	IMAX RPM:	683.1	ITOTAL REV:	1339.60
IAVE TORQ (NM ):	512.9	IAVE RPM:	263.0	IAVE POWER (KW):	14.13

REV/HR IN						TOTAL		TOTAL	
GEAR NAMES						(REVOLUTION)		(EQUIVALENT)	
MEAN	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	DAMAGE	DAMAGE
TORQUE									
LEVEL									
2800.	0.1	7.1	0.1	0.1	9.1	0.1	16.61	0.01	92.41
2500.	0.1	6.1	0.1	0.1	32.1	0.1	37.81	0.01	129.01
2200.	0.1	6.1	0.1	0.1	27.1	0.1	33.21	0.01	48.41
1900.	0.1	26.1	0.1	0.1	74.1	0.1	100.81	0.01	75.51
1600.	0.1	103.1	0.1	0.1	116.1	0.1	218.71	0.01	69.31
1300.	0.1	211.1	0.1	0.1	186.1	0.1	397.41	0.01	39.51
1000.	1.1	649.1	0.1	0.1	275.1	0.1	924.51	0.01	19.91
700.	2.1	1236.1	0.1	0.1	977.1	0.1	2214.51	0.01	8.51
400.	2.1	1516.1	0.1	0.1	561.1	0.1	2079.51	0.01	0.71
100.	32.1	2846.1	0.1	0.1	1133.1	0.1	4011.91	0.01	0.01
-200.	8.1	1642.1	0.1	0.1	393.1	0.1	2043.11	0.01	0.01
-500.	1.1	1207.1	0.1	0.1	306.1	0.1	1514.41	0.01	1.21
-800.	1.1	967.1	0.1	0.1	142.1	0.1	1108.71	0.01	8.31
-1100.	0.1	494.1	0.1	0.1	64.1	0.1	557.81	0.01	22.41
-1400.	0.1	304.1	0.1	0.1	22.1	0.1	325.71	0.01	49.71
-1700.	0.1	170.1	0.1	0.1	0.1	0.1	169.71	0.01	63.11
-2000.	0.1	23.1	0.1	0.1	0.1	0.1	22.81	0.01	19.01
-2300.	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.01	0.21
TOTAL	48.1	11414.1	0.1	0.1	4315.1	0.1	15777.91		
DAMAGE	0.1	313.1	0.1	0.1	337.1	0.1			647.21

\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

OPERATION 5- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:00 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 5 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 11

DATA START TIME: 0.0 SEC.

DATA END TIME: 305.6 SEC.

ITORQ CHN: 5	NAME: RAIT	UNITS: NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL: 8	IREF TORQUE: 2000.00	ISPEED I/O RATIO: 1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL: 3	EXPONENT: 5.350	ITORQUE I/O RATIO: 1.00001	
IMIN TORQ (NM): -3061.1	IMIN RPM: 1.9	ISAMPLES/SEC: 1000.000	
IMAX TORQ (NM): 2361.6	IMAX RPM: 683.1	ITOTAL REV: 1339.60	
IAVE TORQ (NM): 619.9	IAVE RPM: 263.0	IAVE POWER (KW): 17.07	

MEAN TORQUE LEVEL	REV/HR IN GEAR NAMES					TOTAL IREVOLUTIONI PER HOUR		TOTAL DAMAGE EQUIVALENTI DAMAGE	
	NEUT	1F	2F	3F	1R	UNKN		FACTOR	
2300.	0.1	0.1	0.1	0.1	3.1	0.1	3.31	0.01	6.31
2000.	0.1	0.1	0.1	0.1	16.1	0.1	16.41	0.01	15.31
1700.	0.1	0.1	0.1	0.1	36.1	0.1	36.21	0.01	14.91
1400.	1.1	0.1	0.1	0.1	29.1	0.1	29.61	0.01	4.41
1100.	2.1	0.1	0.1	0.1	153.1	0.1	154.91	0.01	4.91
800.	5.1	0.1	0.1	0.1	1010.1	0.1	1014.91	0.01	7.01
500.	2.1	39.1	0.1	0.1	1371.1	0.1	1411.91	0.01	1.11
200.	10.1	239.1	0.1	0.1	929.1	0.1	1178.31	0.01	0.01
-100.	23.1	1972.1	0.1	0.1	574.1	0.1	2568.51	0.01	0.01
-400.	2.1	3252.1	0.1	0.1	88.1	0.1	3341.51	0.01	1.11
-700.	2.1	3335.1	0.1	0.1	36.1	0.1	3372.71	0.01	13.11
-1000.	1.1	1725.1	0.1	0.1	51.1	0.1	1777.01	0.01	41.11
-1300.	1.1	567.1	0.1	0.1	16.1	0.1	583.71	0.01	54.61
-1600.	0.1	220.1	0.1	0.1	2.1	0.1	222.81	0.01	64.01
-1900.	0.1	57.1	0.1	0.1	0.1	0.1	57.21	0.01	37.61
-2200.	0.1	8.1	0.1	0.1	0.1	0.1	7.91	0.01	11.11
-2500.	0.1	0.1	0.1	0.1	0.1	0.1	0.51	0.01	1.41
-2800.	0.1	0.1	0.1	0.1	0.1	0.1	0.21	0.01	1.11
-3100.	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.01	1.21
TOTAL	48.1	11414.1	0.1	0.1	4316.1	0.1	15777.91		
DAMAGE	1.1	222.1	0.1	0.1	57.1	0.1			280.31

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

OPERATION 5 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 0:41 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 8 MIN 48 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 10

DATA START TIME: 0.0 SEC.

DATA END TIME: 528.6 SEC.

ITORQ CHN: 4	INAME : FAIT	IUNITS: NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL: 8	IREF TORQUE: 2000.00	ISPEED I/O RATIO: 1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL: 3	IEXPONENT: 5.350	ITORQUE I/O RATIO: 1.00001	

IMIN TORQ (NM ):	-2499.2	IMIN RPM:	0.1	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	3196.7	IMAX RPM:	698.0	ITOTAL REV:	1173.95
IAVE TORQ (NM ):	295.2	IAVE RPM:	133.3	IAVE POWER (KW):	4.12

MEAN	REV/HR IN					TOTAL		TOTAL	
TORQUE	GEAR NAMES					REVOLUTION	DAMAGE	EQUIVALENT	
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
2800.	0.1	0.1	0.1	0.1	18.1	0.1	17.61	0.01	107.01
2500.	0.1	0.1	0.1	0.1	22.1	0.1	22.31	0.01	74.81
2200.	0.1	0.1	2.1	0.1	12.1	0.1	14.01	0.01	26.31
1900.	0.1	0.1	4.1	0.1	21.1	0.1	25.01	0.01	19.41
1600.	0.1	0.1	10.1	0.1	32.1	0.1	41.91	0.01	11.71
1300.	0.1	0.1	68.1	0.1	137.1	0.1	204.71	0.01	19.21
1000.	1.1	0.1	299.1	0.1	294.1	0.1	594.51	0.01	14.01
700.	3.1	1.1	540.1	0.1	451.1	0.1	994.31	0.01	4.01
400.	2.1	0.1	704.1	0.1	246.1	0.1	952.51	0.01	0.31
100.	8.1	2.1	1108.1	0.1	766.1	0.1	1885.11	0.01	0.01
-200.	2.1	2.1	651.1	0.1	380.1	0.1	1033.71	0.01	0.01
-500.	1.1	1.1	610.1	0.1	171.1	0.1	782.31	0.01	0.61
-800.	0.1	0.1	558.1	0.1	82.1	0.1	641.71	0.01	5.91
-1100.	0.1	0.1	352.1	0.1	43.1	0.1	395.21	0.01	15.21
-1400.	1.1	0.1	234.1	0.1	21.1	0.1	255.11	0.01	39.31
-1700.	0.1	0.1	103.1	0.1	7.1	0.1	109.91	0.01	39.81
-2000.	0.1	0.1	18.1	0.1	0.1	0.1	18.71	0.01	17.31
-2300.	0.1	0.1	5.1	0.1	0.1	0.1	4.91	0.01	8.21
-2600.	0.1	0.1	0.1	0.1	0.1	0.1	0.11	0.01	0.21
TOTAL	18.1	8.1	5265.1	0.1	2702.1	0.1	7997.71		
DAMAGE	0.1	1.1	142.1	0.1	277.1	0.1			403.21



1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

# OPERATION 5- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 0:41 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 8 MIN 48 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 10

DATA START TIME: 0.0 SEC.

DATA END TIME: 528.6 SEC.

ITORQ CHN:	5	NAME :	RAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	REF TORQUE:	2000.00	SPEED I/O RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	TORQUE I/O RATIO:	1.0000	
IMIN TORQ (NM ):	-3241.0	MIN RPM:	0.1	SAMPLES/SEC:	1000.000	
IMAX TORQ (NM ):	1808.3	MAX RPM:	698.0	TOTAL REV:	1173.95	
IAVE TORQ (NM ):	354.4	AVE RPM:	133.3	AVE POWER (KW):	4.94	

MEAN	REV/HR IN					TOTAL	TOTAL
TORQUE	GEAR NAMES					REVOLUTION	DAMAGE
LEVEL	NEUT	1F	2F	3F	1R	PER HOUR	EQUIVALENT
							DAMAGE
1700.	0.1	0.1	0.1	0.1	2.1	0.1	0.61
1400.	0.1	0.1	0.1	0.1	15.1	0.1	2.31
1100.	2.1	0.1	4.1	0.1	124.1	0.1	4.41
800.	2.1	0.1	10.1	0.1	502.1	0.1	3.41
500.	3.1	0.1	16.1	0.1	844.1	0.1	0.81
200.	1.1	1.1	57.1	0.1	559.1	0.1	0.01
-100.	4.1	2.1	982.1	0.1	473.1	0.1	0.01
-400.	1.1	1.1	1507.1	0.1	82.1	0.1	0.51
-700.	1.1	1.1	1480.1	0.1	51.1	0.1	6.01
-1000.	1.1	1.1	774.1	0.1	33.1	0.1	21.41
-1300.	1.1	1.1	349.1	0.1	11.1	0.1	32.91
-1600.	1.1	0.1	71.1	0.1	3.1	0.1	20.31
-1900.	1.1	0.1	12.1	0.1	3.1	0.1	11.91
-2200.	0.1	0.1	4.1	0.1	3.1	0.1	10.91
-2500.	0.1	0.1	0.1	0.1	0.1	0.1	2.51
-2800.	0.1	0.1	0.1	0.1	0.1	0.1	2.91
-3100.	0.1	0.1	0.1	0.1	0.1	0.1	4.71
TOTAL	18.1	8.1	5265.1	0.1	2704.1	0.1	
DAMAGE	4.1	7.1	95.1	0.1	20.1	0.1	125.61

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:.....

# OPERATION 6 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:26 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 3 MIN 27 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 14

DATA START TIME: 0.0 SEC.

DATA END TIME: 207.6 SEC.

ITORQ CHN:	4	NAME :	FAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	IREF TORQUE:	2000.00	ISPEED I/O RATIO:	1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	IEXPONENT:	5.350	ITORQUE I/O RATIO:	1.00001	

IMIN TORQ (NM ):	-2589.6	IMIN RPM:	168.8	ISAMPLES/SEC:	1000.000
IMAX TORQ (NM ):	2645.4	IMAX RPM:	481.8	ITOTAL REV:	1381.99
IAVE TORQ (NM ):	446.7	IAVE RPM:	399.4	IAVE POWER (KW):	18.68

MEAN	REV/HR IN					TOTAL	TOTAL
TORQUE	GEAR NAMES					IREVOLUTION	DAMAGE
LEVEL	NEUT	1F	2F	3F	1R	PER HOUR	EQUIVALENT
							DAMAGE
2500.	0.1	9.1	0.1	0.1	9.1	0.1	54.61
2200.	0.1	13.1	0.1	0.1	16.1	0.1	46.61
1900.	0.1	18.1	0.1	0.1	68.1	0.1	63.61
1600.	0.1	20.1	0.1	0.1	89.1	0.1	36.91
1300.	0.1	144.1	0.1	0.1	119.1	0.1	25.91
1000.	0.1	312.1	0.1	0.1	232.1	0.1	12.21
700.	0.1	751.1	0.1	0.1	667.1	0.1	5.11
400.	0.1	1134.1	0.1	0.1	1060.1	0.1	0.61
100.	0.1	3852.1	0.1	0.1	3213.1	0.1	0.01
-200.	0.1	1893.1	0.1	0.1	2093.1	0.1	0.11
-500.	0.1	1963.1	0.1	0.1	1833.1	0.1	2.91
-800.	0.1	1410.1	0.1	0.1	1068.1	0.1	19.11
-1100.	0.1	693.1	0.1	0.1	434.1	0.1	42.81
-1400.	0.1	297.1	0.1	0.1	171.1	0.1	68.91
-1700.	0.1	156.1	0.1	0.1	85.1	0.1	100.51
-2000.	0.1	56.1	0.1	0.1	41.1	0.1	91.31
-2300.	0.1	23.1	0.1	0.1	9.1	0.1	62.51
-2600.	0.1	5.1	0.1	0.1	6.1	0.1	35.21
TOTAL	0.1	12748.1	0.1	0.1	11213.1	0.1	
DAMAGE	0.1	350.1	0.1	0.1	319.1	0.1	668.51

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE: \_\_\_\_\_

**OPERATION 6 - REAR AXLE INPUT SHAFT**

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 1:26 6JUN88

ENGINEER: BORDEWICK

RUN TIME: 3 MIN 27 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 14

DATA START TIME: 0.0 SEC.

DATA END TIME: 207.6 SEC.

ITORD CHN: 5	INAME: RAIT	IUNITS: NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL: 8	IREF TORQUE: 2000.00	ISPEED I/O RATIO: 1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL: 3	IEXPONENT: 5.350	ITORQUE I/O RATIO: 1.00001	

IMIN TORQ (NM): -2759.7	IMIN RPM: 168.8	ISAMPLES/SEC: 1000.000
IMAX TORQ (NM): 976.1	IMAX RPM: 481.8	ITOTAL REV: 1381.99
IAVE TORQ (NM): 363.1	IAVE RPM: 399.4	IAVE POWER (KW): 15.19

MEAN	REV/HR IN					TOTAL	TOTAL	
TORQUE	GEAR NAMES					(REVOLUTION)	DAMAGE	EQUIVALENT
LEVEL	NEUT	(1F)	2F	3F	(1R)	UNKN	PER HOUR	FACTOR
800.	0.1	6.1	0.1	0.1	17.1	0.1	22.81	0.01
500.	0.1	33.1	0.1	0.1	59.1	0.1	92.51	0.01
200.	0.1	283.1	0.1	0.1	370.1	0.1	652.81	0.01
-100.	0.1	5955.1	0.1	0.1	5536.1	0.1	11491.71	0.01
-400.	0.1	3058.1	0.1	0.1	3119.1	0.1	6177.01	0.01
-700.	0.1	1928.1	0.1	0.1	1345.1	0.1	3273.51	0.01
-1000.	0.1	864.1	0.1	0.1	473.1	0.1	1336.71	0.01
-1300.	0.1	318.1	0.1	0.1	133.1	0.1	450.81	0.01
-1600.	0.1	148.1	0.1	0.1	79.1	0.1	226.31	0.01
-1900.	0.1	128.1	0.1	0.1	35.1	0.1	162.71	0.01
-2200.	0.1	14.1	0.1	0.1	35.1	0.1	49.01	0.01
-2500.	0.1	10.1	0.1	0.1	11.1	0.1	20.81	0.01
-2800.	0.1	4.1	0.1	0.1	0.1	0.1	4.21	0.01
TOTAL	0.1	12748.1	0.1	0.1	11213.1	0.1	23961.21	
DAMAGE	0.1	273.1	0.1	0.1	162.1	0.1		434.81

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

# OPERATION 7 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE  
FILE NAME: T1FORKL  
ENGINEER: BORDEWICK  
CONDITIONS: HOT DRY  
OPERATION: \*  
DATA START TIME: 0.0 SEC.

EIR: .  
DATE: 0:11 6JUL88  
RUN TIME: 5 MIN 33 SEC  
TEST: LOW SPEED TORQUE HISTORY  
COMPOSITE %: 0.0; RUN: 15  
DATA END TIME: 333.0 SEC.

ITORQ CHN: 4 INAME: FAIT IUNITS: NM I DAMAGE CALCULATED USING:  
ICOMMAND CHANNEL: 8 IREF TORQUE: 2000.00 ISPEED I/O RATIO: 1.00001 TORQUE AT EACH DATA POINT  
ISPEED CHANNEL: 3 IEXPONENT: 5.350 ITORQUE I/O RATIO: 1.00001

IMIN TORQ (NM ): -3183.7 IMIN RPM: 0.0 ISAMPLES/SEC: 1000.000 I  
IMAX TORQ (NM ): 2719.2 IMAX RPM: 475.3 ITOTAL REV: 1764.76 I  
IAVE TORQ (NM ): 673.1 IAVE RPM: 318.0 IAVE POWER (KW): 22.41 I

MEAN		REV/HR IN					TOTAL		TOTAL	
TORQUE		GEAR NAMES					IREVOLUTIONI		DAMAGE	
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE	
2500.	0.1	11.1	0.1	0.1	7.1	0.1	18.41	0.01	65.61	
2200.	0.1	17.1	0.1	0.1	4.1	0.1	21.11	0.01	34.21	
1900.	0.1	44.1	0.1	0.1	3.1	0.1	47.41	0.01	32.51	
1600.	0.1	135.1	0.1	0.1	3.1	0.1	137.51	0.01	40.51	
1300.	0.1	405.1	0.1	0.1	9.1	0.1	414.61	0.01	39.71	
1000.	0.1	860.1	0.1	0.1	20.1	0.1	880.01	0.01	21.01	
700.	0.1	1846.1	0.1	0.1	29.1	0.1	1875.51	0.01	7.51	
400.	0.1	2526.1	0.1	0.1	49.1	0.1	2574.71	0.01	0.71	
100.	0.1	4039.1	0.1	0.1	72.1	0.1	4111.21	0.01	0.01	
-200.	0.1	1808.1	0.1	0.1	53.1	0.1	1861.01	0.01	0.01	
-500.	0.1	1734.1	0.1	0.1	22.1	0.1	1756.11	0.01	1.51	
-800.	0.1	1756.1	0.1	0.1	8.1	0.1	1764.61	0.01	14.31	
-1100.	0.1	1298.1	0.1	0.1	32.1	0.1	1329.81	0.01	55.01	
-1400.	0.1	1063.1	0.1	0.1	39.1	0.1	1102.01	0.01	168.61	
-1700.	0.1	737.1	0.1	0.1	47.1	0.1	783.51	0.01	318.41	
-2000.	0.1	248.1	0.1	0.1	6.1	0.1	254.01	0.01	250.41	
-2300.	0.1	77.1	0.1	0.1	4.1	0.1	80.51	0.01	149.11	
-2600.	0.1	18.1	0.1	0.1	0.1	0.1	18.51	0.01	76.61	
-2900.	0.1	40.1	0.1	0.1	0.1	0.1	39.81	0.01	307.81	
-3200.	0.1	6.1	0.1	0.1	0.1	0.1	5.81	0.01	60.01	
TOTAL	0.1	18667.1	0.1	0.1	409.1	0.1	19077.41			
DAMAGE	0.1	1574.1	0.1	0.1	78.1	0.1			1643.21	

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

OPERATION 7- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 0:11 6JUL88

ENGINEER: BORDEWICK

RUN TIME: 5 MIN 33 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: \*

COMPOSITE %: 0.0; RUN: 15

DATA START TIME: 0.0 SEC.

DATA END TIME: 333.0 SEC.

ITORQ CHN: 5	NAME: RAIT	UNITS: NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL: 8	IREF TORQUE: 2000.00	ISPEED I/O RATIO: 1.00001	TORQUE AT EACH DATA POINT
ISPEED CHANNEL: 3	EXPONENT: 5.350	ITORQUE I/O RATIO: 1.00001	

IMIN TORQ (NM): -2902.3	IMIN RPM: 0.0	ISAMPLES/SEC: 1000.000
IMAX TORQ (NM): 507.3	IMAX RPM: 475.3	ITOTAL REV: 1764.76
IAVE TORQ (NM): 500.7	IAVE RPM: 318.0	IAVE POWER (KW): 16.67

MEAN TORQUE LEVEL	NEUT	1F	2F	3F	1R	UNKN	TOTAL REVOLUTION PER HOUR	TOTAL DAMAGE FACTOR	TOTAL EQUIVALENT DAMAGE
500.	0.1	26.1	0.1	0.1	1.1	0.1	26.91	0.01	0.01
200.	0.1	332.1	0.1	0.1	9.1	0.1	341.01	0.01	0.01
-100.	0.1	5923.1	0.1	0.1	116.1	0.1	6039.31	0.01	0.01
-400.	0.1	5549.1	0.1	0.1	91.1	0.1	5640.01	0.01	1.61
-700.	0.1	3928.1	0.1	0.1	83.1	0.1	4011.41	0.01	15.01
-1000.	0.1	1721.1	0.1	0.1	34.1	0.1	1755.01	0.01	41.21
-1300.	0.1	640.1	0.1	0.1	22.1	0.1	662.21	0.01	64.61
-1600.	0.1	282.1	0.1	0.1	52.1	0.1	334.11	0.01	95.71
-1900.	0.1	141.1	0.1	0.1	0.1	0.1	141.81	0.01	107.01
-2200.	0.1	86.1	0.1	0.1	0.1	0.1	86.81	0.01	139.21
-2500.	0.1	28.1	0.1	0.1	0.1	0.1	27.71	0.01	86.71
-2800.	0.1	12.1	0.1	0.1	0.1	0.1	11.61	0.01	63.91
TOTAL	0.1	18669.1	0.1	0.1	409.1	0.1	19077.41		
DAMAGE	0.1	596.1	0.1	0.1	19.1	0.1			614.81

18 REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL #1

PAGE: 10F 1; TABLE:-----

# OPERATION 12 - FRONT AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 4:14 2JUN88

ENGINEER: BORDEWICK

RUN TIME: 0 MIN 9 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: CLIMB 45 PERCENT SLOPE

COMPOSITE %: 0.0; RUN: 4

DATA START TIME: 0.0 SEC.

DATA END TIME: 9.9 SEC.

ITORQ CHN:	4	NAME :	FAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	REF TORQUE:	2000.00	ISPEED I/O RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	TORQUE I/O RATIO:	1.0000	
IMIN TORQ (NM ):	-3576.2	IMIN RPM:	0.0	ISAMPLES/SEC:	1000.000	
IMAX TORQ (NM ):	-1647.1	IMAX RPM:	371.6	ITOTAL REV:	47.74	
IAVE TORQ (NM ):	2697.7	IAVE RPM:	290.2	IAVE POWER (KW):	81.98	

MEAN	REV/HR IN	TOTAL	TOTAL
TORQUE	GEAR NAMES	IREVOLUTION	DAMAGE IEQUIVALENT
LEVEL	NEUT 1F 2F 3F 1R UNKN	PER HOUR	FACTOR DAMAGE
-1700.	0.1 14.1 0.1 0.1 0.1 0.1	14.21	0.01 6.51
-2000.	0.1 379.1 0.1 0.1 0.1 0.1	379.31	0.01 481.51
-2300.	0.1 1484.1 0.1 0.1 0.1 0.1	1484.11	0.01 3249.31
-2600.	0.1 6769.1 0.1 0.1 0.1 0.1	6768.51	0.01 28243.91
-2900.	0.1 5732.1 0.1 0.1 0.1 0.1	5731.51	0.01 40547.01
-3200.	0.1 2692.1 0.1 0.1 0.1 0.1	2692.31	0.01 31483.31
-3500.	0.1 342.1 0.1 0.1 0.1 0.1	342.21	0.01 6088.81
TOTAL	0.1 17412.1 0.1 0.1 0.1 0.1	17412.21	1 110100.41
DAMAGE	0.1 110100.1 0.1 0.1 0.1 0.1		

1\* REVOLUTIONS PER HOUR AND EQUIVALENT DAMAGE AT TORQUE LEVEL \*1

PAGE: 10F 1; TABLE:-----

OPERATION 12- REAR AXLE INPUT SHAFT

MACHINE: SDMHE

EIR: .

FILE NAME: T1FORKL

DATE: 4:14 2JUN88

ENGINEER: BORDEWICK

RUN TIME: 0 MIN 9 SEC

CONDITIONS: HOT DRY

TEST: LOW SPEED TORQUE HISTORY

OPERATION: CLIMB 45 PERCENT SLOPE

COMPOSITE %: 0.0; RUN: 4

DATA START TIME: 0.0 SEC.

DATA END TIME: 9.9 SEC.

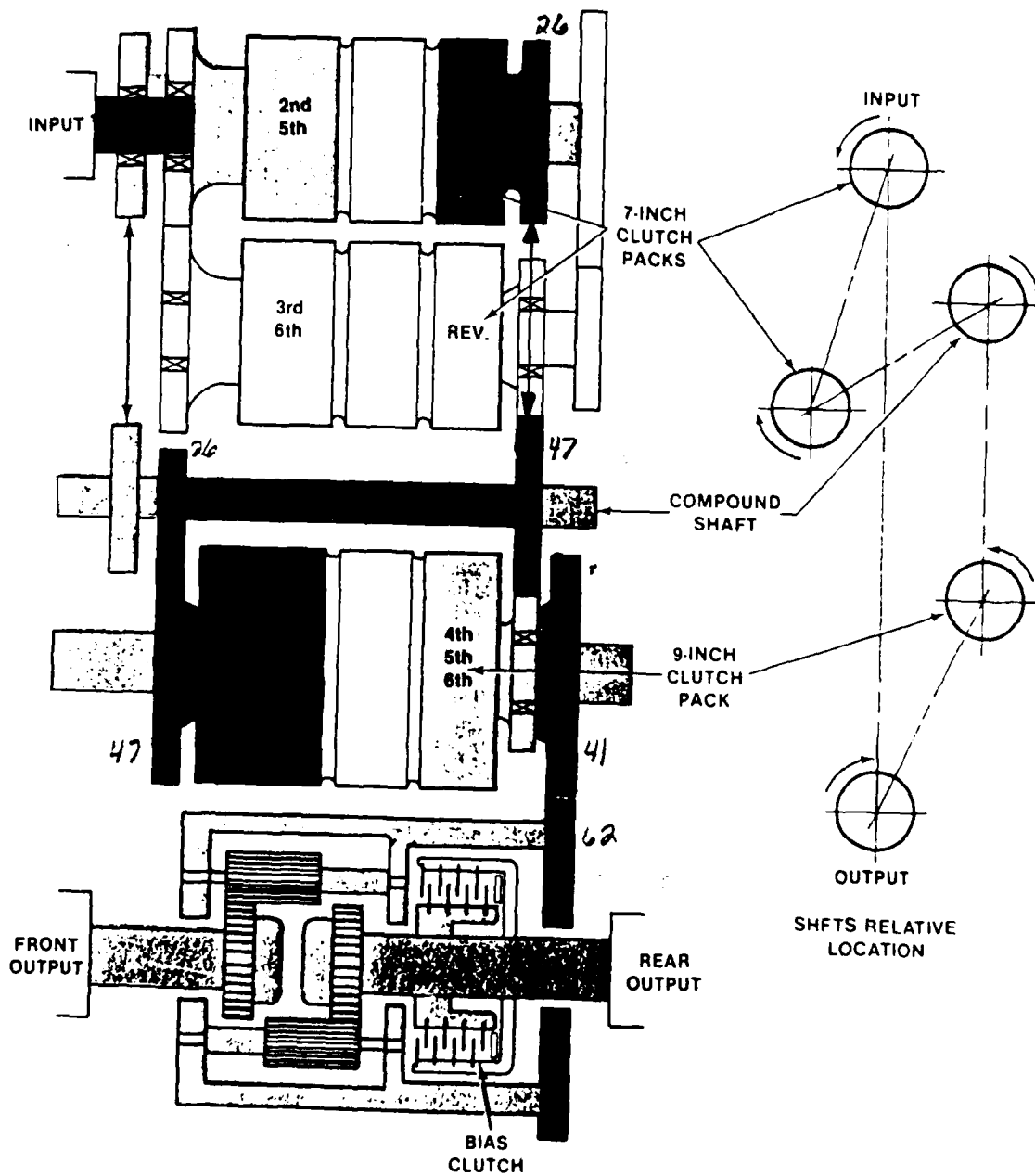
ITRQ CHN:	5	NAME :	RAIT	UNITS:	NM	DAMAGE CALCULATED USING:
ICOMMAND CHANNEL:	8	REF TORQUE:	2000.00	SPEED I/O RATIO:	1.0000	TORQUE AT EACH DATA POINT
ISPEED CHANNEL:	3	EXPONENT:	5.350	TORQUE I/O RATIO:	1.0000	
IMIN TORQ (NM ):	-3477.4	IMIN RPM:	0.0	SAMPLES/SEC:	1000.000	
IMAX TORQ (NM ):	-983.1	IMAX RPM:	371.6	TOTAL REV:	47.74	
IAVE TORQ (NM ):	2499.7	IAVE RPM:	290.2	IAVE POWER (KW):	75.96	

MEAN	REV/HR IN						TOTAL	TOTAL	
TORQUE	GEAR NAMES						IREVOLUTION	DAMAGE	EQUIVALENT
LEVEL	NEUT	1F	2F	3F	1R	UNKN	PER HOUR	FACTOR	DAMAGE
-1000.	0.1	12.1	0.1	0.1	0.1	0.1	12.21	0.01	0.41
-1300.	0.1	129.1	0.1	0.1	0.1	0.1	128.61	0.01	18.01
-1600.	0.1	125.1	0.1	0.1	0.1	0.1	125.41	0.01	33.51
-1900.	0.1	415.1	0.1	0.1	0.1	0.1	414.71	0.01	379.61
-2200.	0.1	2310.1	0.1	0.1	0.1	0.1	2309.81	0.01	4663.81
-2500.	0.1	8593.1	0.1	0.1	0.1	0.1	8593.21	0.01	28243.11
-2800.	0.1	3098.1	0.1	0.1	0.1	0.1	3097.51	0.01	18340.21
-3100.	0.1	2327.1	0.1	0.1	0.1	0.1	2327.21	0.01	22904.11
-3400.	0.1	404.1	0.1	0.1	0.1	0.1	403.51	0.01	6549.11
TOTAL	0.1	17412.1	0.1	0.1	0.1	0.1	17412.21		
DAMAGE	0.1	81132.1	0.1	0.1	0.1	0.1			81131.81

1F

1500

# POWER FLOW



$$\text{TORQUE INCREASE RATIO} = \frac{47}{26} \times \frac{47}{26} \times \frac{62}{41} = 4.941$$

$$\text{SPEED INCREASE RATIO} = \frac{26}{47} \times \frac{26}{47} \times \frac{41}{62} = .202$$

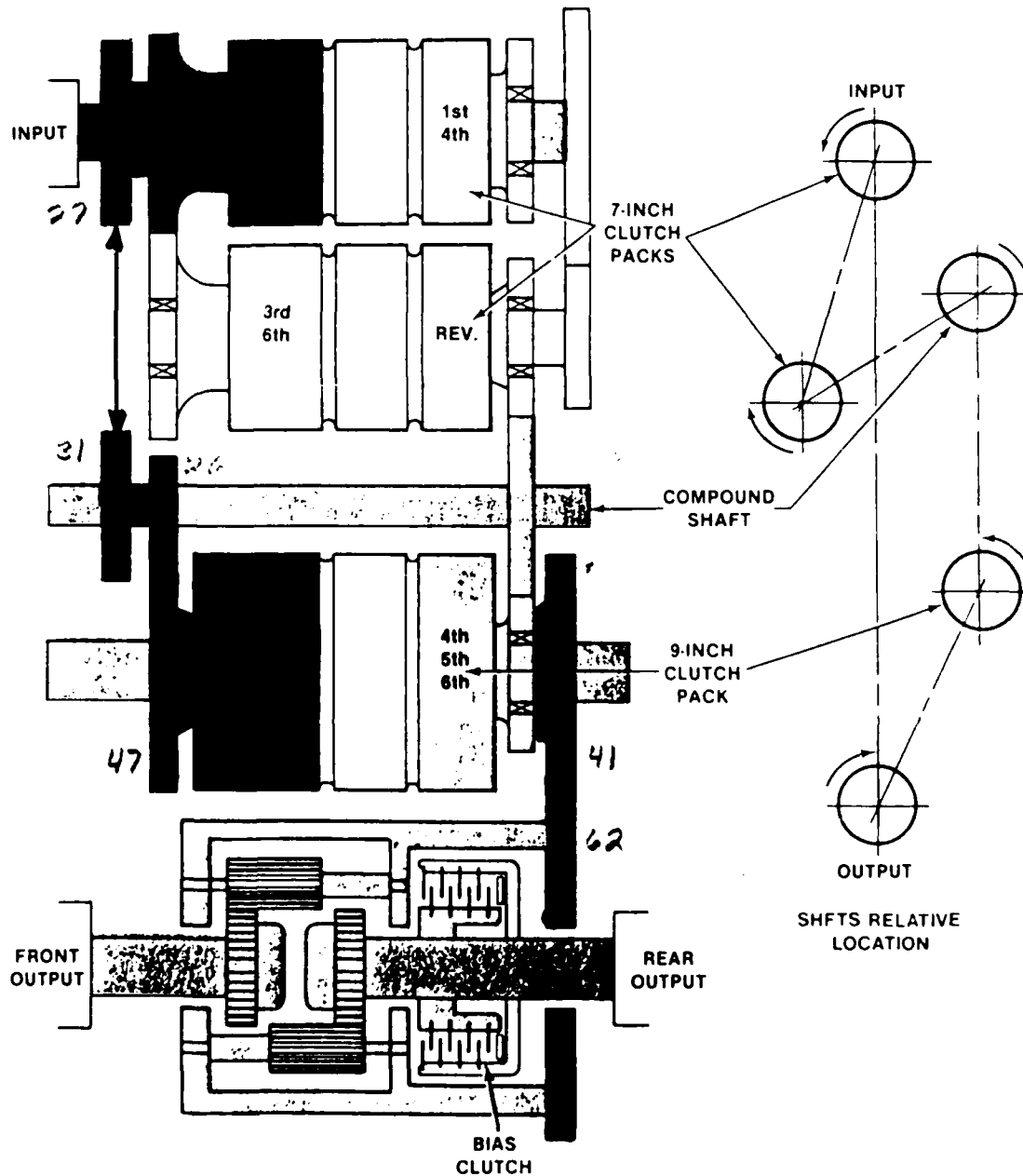
Figure 2-9. Power Flow — Range Forward.

A-30 1st



2F

# POWER FLOW



$$\text{TORQUE INCREASE RATIO} = \frac{31}{27} \times \frac{47}{26} \times \frac{62}{41} = 3.138$$

$$\text{SPEED INCREASE RATIO} = \frac{27}{31} \times \frac{26}{47} \times \frac{41}{62} = .318$$

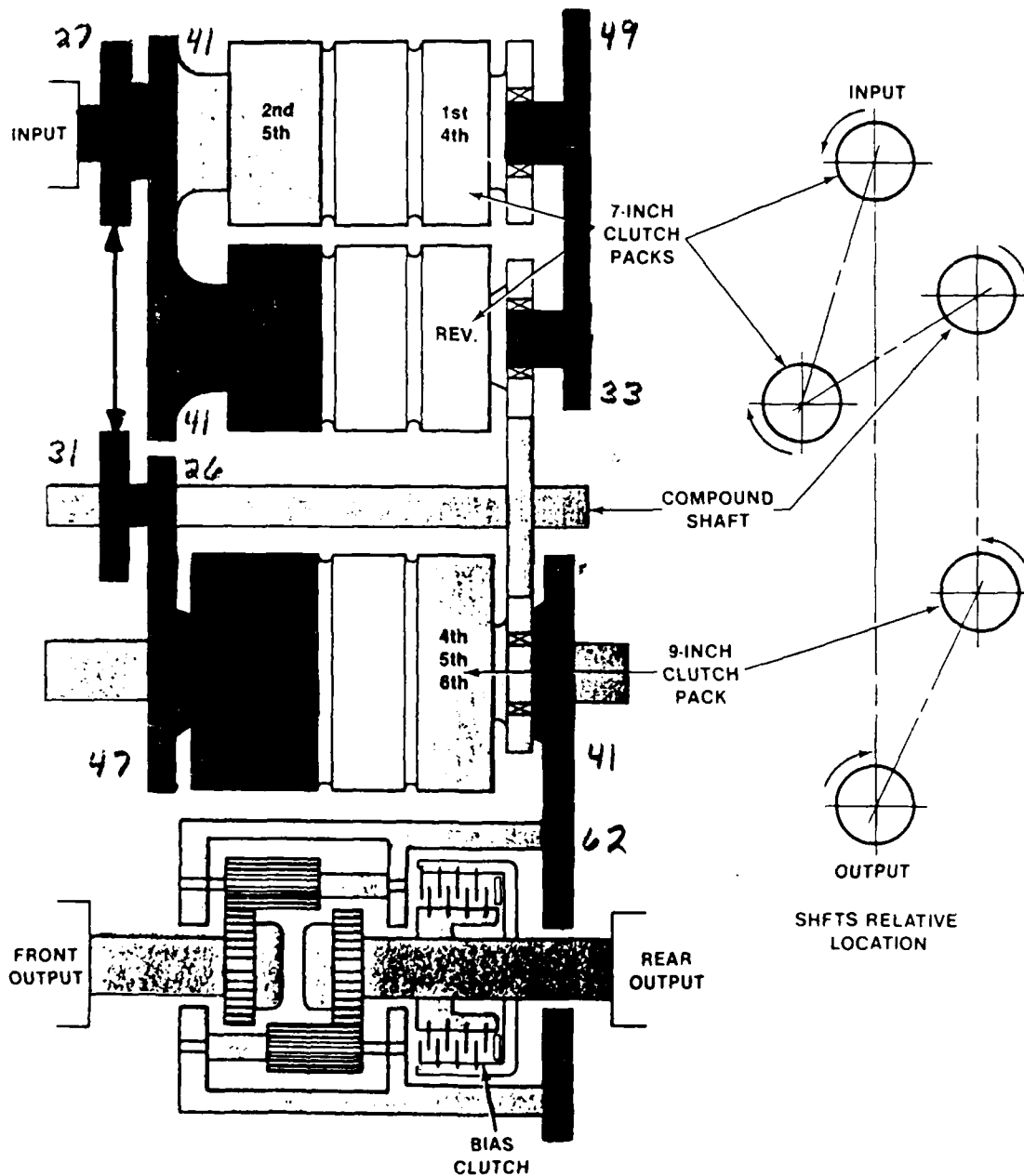
Power Flow — ~~Rev~~ Range Forward.

A-31

2ND

3 F

# POWER FLOW



$$\text{TORQUE INCREASE RATIO} = \frac{33}{49} \times \frac{41}{41} \times \frac{31}{27} \times \frac{47}{26} \times \frac{62}{41} = 2.114$$

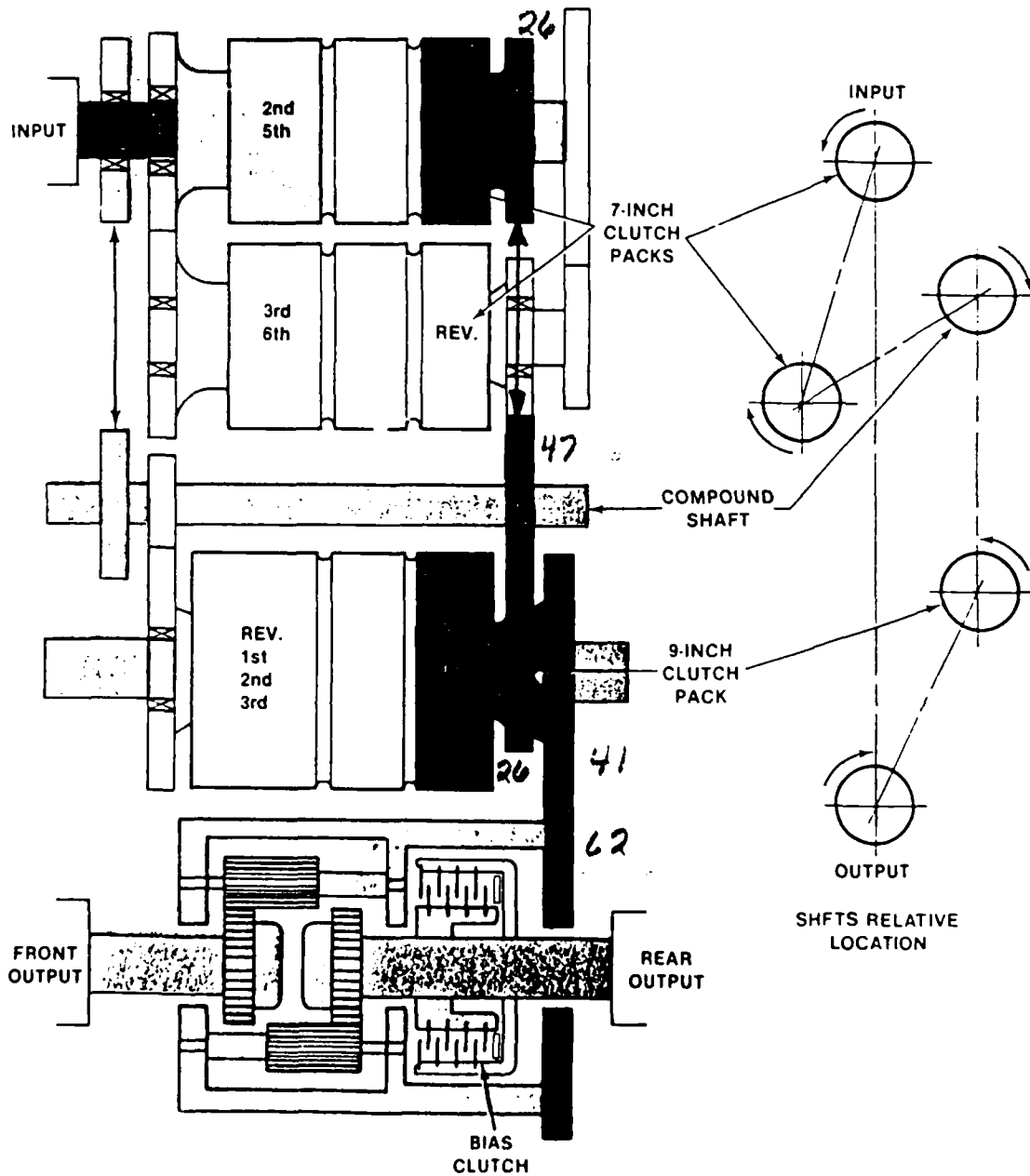
$$\text{SPEED INCREASE RATIO} = \frac{49}{33} \times \frac{41}{41} \times \frac{27}{31} \times \frac{26}{47} \times \frac{41}{62} = .473$$

Power Flow — Range Forward.

A-32 3A0

4 F

# POWER FLOW



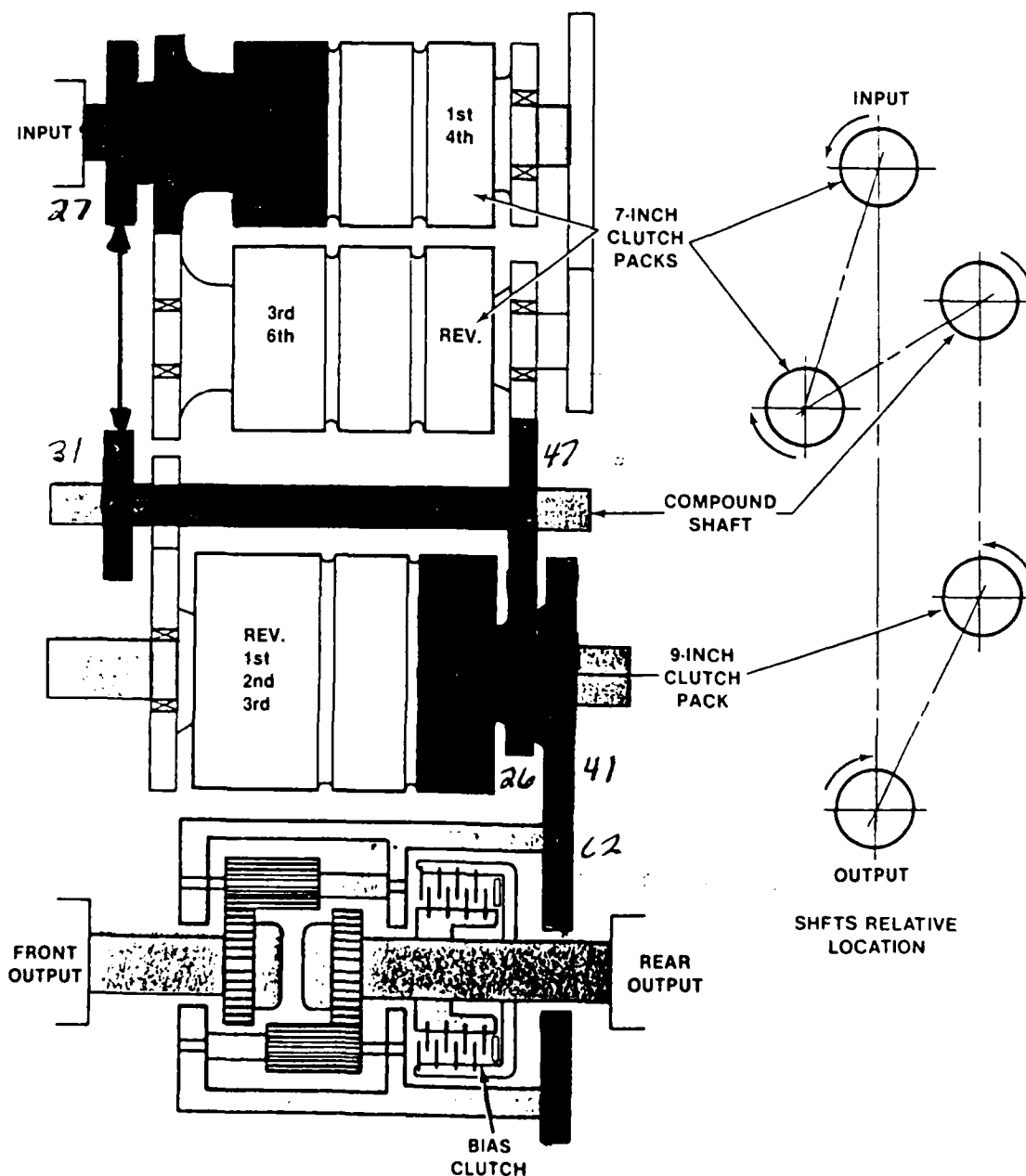
$$\text{TORQUE INCREASE RATIO} = \frac{47}{26} \times \frac{26}{47} \times \frac{62}{41} = 1.512$$

$$\text{SPEED INCREASE RATIO} = \frac{26}{47} \times \frac{47}{26} \times \frac{41}{62} = .661$$

Power Flow — Range Forward.

5F

# POWER FLOW



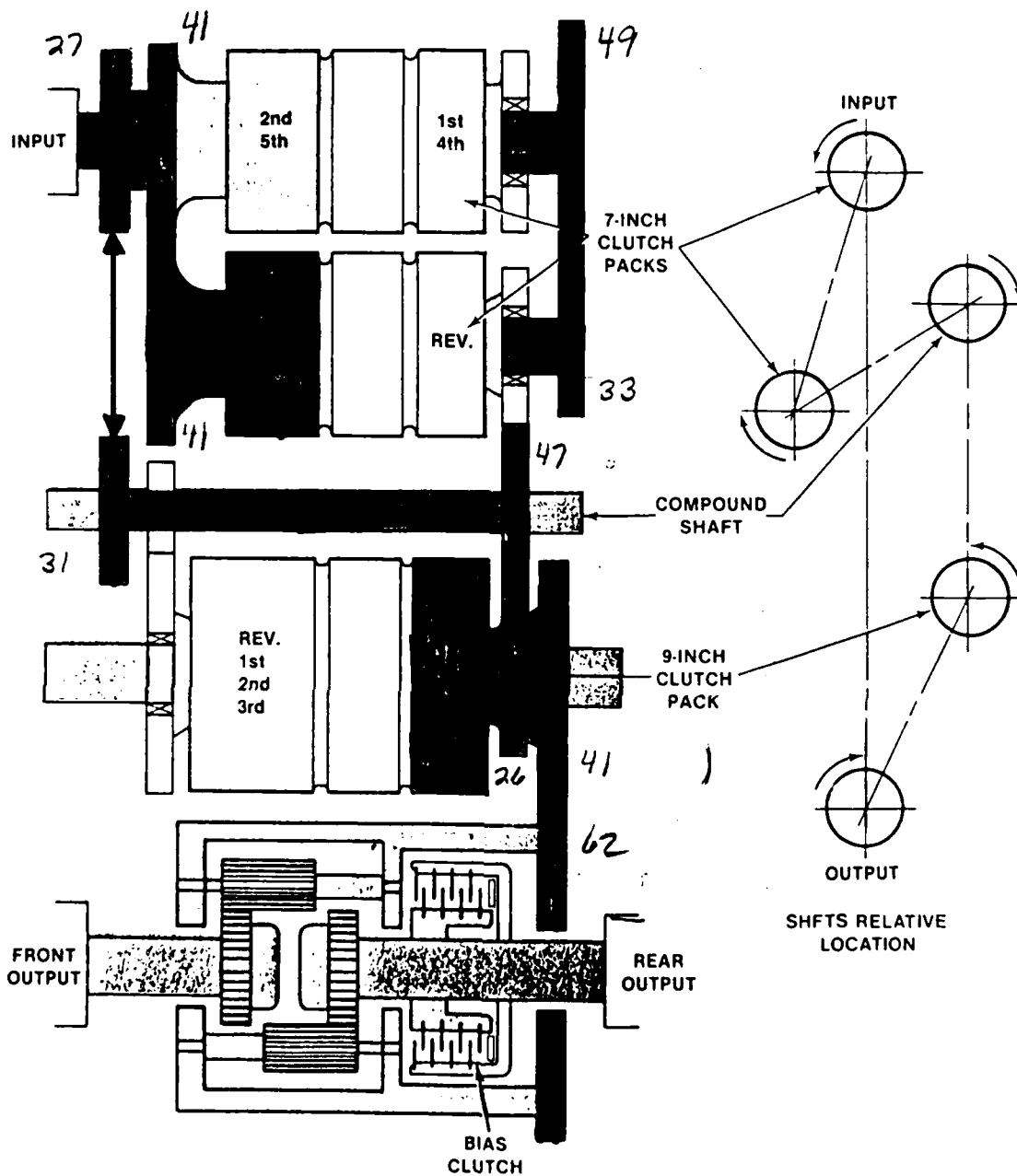
$$\text{TORQUE INCREASE RATIO} = \frac{31}{27} \times \frac{26}{47} \times \frac{62}{41} = .961$$

$$\text{SPEED INCREASE RATIO} = \frac{27}{31} \times \frac{47}{26} \times \frac{41}{62} = 1.041$$

Power Flow — ~~5th~~ Range Forward.

6F

# POWER FLOW



$$\text{TORQUE INCREASE RATIO} = \frac{33}{49} \times \frac{41}{41} \times \frac{31}{27} \times \frac{26}{47} \times \frac{62}{41} = .647$$

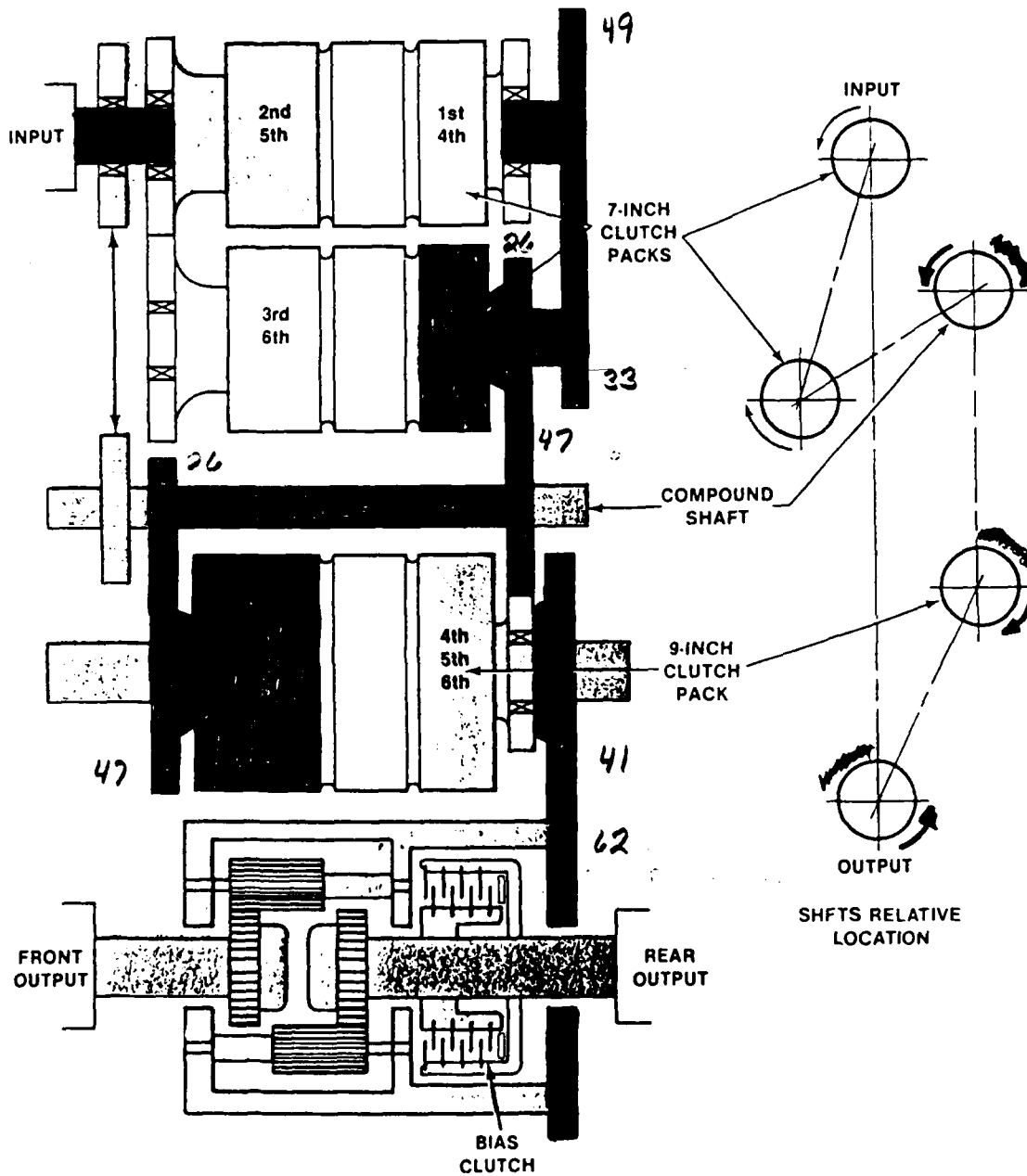
$$\text{SPEED INCREASE RATIO} = \frac{49}{33} \times \frac{41}{41} \times \frac{27}{31} \times \frac{47}{26} \times \frac{41}{62} = 1.546$$

Power Flow — 4th Range Forward.

A-35 6TN

1 R

# POWER FLOW



$$\text{TORQUE INCREASE RATIO} = \frac{33}{49} \times \frac{47}{26} \times \frac{47}{26} \times \frac{62}{41} = 3.328$$

$$\text{SPEED INCREASE RATIO} = \frac{49}{33} \times \frac{26}{47} \times \frac{26}{47} \times \frac{41}{62} = .300$$

Power Flow — Range  
1st Reverse